EFFECT OF SOIL ADDITIVES ON SOIL MOISTURE CONSERVATION AND LEGUME-CEREAL PERFORMANCE UNDER RAINFED CONDITIONS

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by

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CERTIFICATION

I hereby undertake that this research is an original one and no part of this thesis falls under plagiarism. If found otherwise at any stage I will be responsible for the consequences.

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(IN THE NAME OF ALLAH, THE MOST MERCIFUL, THE MOST BENEFICIAL)

DEDICATION

I DEDICATE THIS WHOLE EFFORT TO

MY PARENTSAND ALL FAMILY MEMBERS

WHO ALWAYS HELPED AND MOTIVATED ME

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(MUHAMMAD SOHAIL-UR-RAZA)

AUTHOR

List of Abbreviations

%	=	Percent
HI	=	Harvest index
I	=	Inoculation
IA	=	Intercropping advantage
K	=	Potassium
kg	=	kilogram
Kg ha^{-1}	=	kilogram per hectare
LSD	=	Least significant difference
m^{-2}	=	Per square meter
MC	=	Marginal cost
Mg	=	Mega gram
MNB	=	Marginal net benefit
MRR	=	Marginal rate of return
NAR	=	Net assimilation rate
NB	=	Net benefit
P	=	Phosphorus
Y	=	Year
pH	=	Soil reaction
FYM	=	Farmyard manure
R.H	=	Relative humidity
RCC	=	Relative crowding co efficient
TCV	=	Total cost that vary
TDM	=	Total dry matter
WUE	=	Water use efficiency
CS	=	Cropping systems
CS1	=	Summer Fallow
CS2	=	Mungbean
CS3	=	Sorghum
CS4	=	Sorghum + mungbean
SA	=	Soil Additives
SA1	=	Control
SA2	=	Qemisoyl @15 kg ha^{-1}(0.015 Mg ha^{-1})
SA3	=	Farm Yard Manure @ 25 Mg ha^{-1}
SA4	=	Compost @ 0.75 Mg ha^{-1}
SA5	=	Gypsum @ 2.5 Mg ha^{-1}

ABSTRACT

The present two years study (2010-11 and 2011-12) was conducted at research area of PMAS-Arid Agriculture University Rawalpindi (AAUR) to test various soil additives for soil moisture conservation under different cropping systems, 2) find out an appropriate cropping system for efficient resource utilization and increase production per unit area and 3) compare the profitability of different soil additives and cropping systems. The field experiment was laid out in a Randomized Complete Block Design with split plot arrangements keeping cropping systems in main plots and soil additives in subplots. The cropping systems included summer fallow-wheat, mungbean-wheat, sorghum-wheat, and sorghum + Mungbean–Wheat (Mungbean was intercropped in sorghum). Soil additives i.e. farm yard manure, gypsum, compost and hydrogel (Qemisoyl) were applied in third week of June 2010 @ 25 t ha^{-1}, 2.5 t ha^{-1}, 0.75 t ha^{-1} and 15 kg ha^{-1}, respectively about two week before the onset of monsoon. During the study period data on soil moisture content, bulk density, crop growth, yield and yield components for all the crops were recorded. Competitive indices, and water use efficiency was also calculated. The data was subjected to Fisher's Analysis of Variance Technique (ANOVA) using statistical package STATISTIX 8.1. Least Significant Difference (LSD) test was used for comparison of treatment means. Economic analysis was performed using partial budget and dominance analysis techniques. The data revealed that at the time of wheat sowing after fellow or summer grown mungbean/sorghum, hydrogel (Qemisoyl) conserved higher moisture content (16.42%) in the soil profile as compared to control (12.80%). It was followed by compost, FYM and Gypsum. Among cropping systems, Mungbean-Wheat cropping

system had slightly higher soil moisture content (15.1%) as compared to summer fellow (14.4%). Minimum soil moisture was recorded in Sorghum-Wheat system (13.2%). The moisture content in intercropping system was at par with fallow-wheat system. The values of competitive indices i.e. Land Equivalent Ratio, Relative Crowding Coefficient, and Competitive Ratio indicated sorghum/mungbean-wheat intercropping system as the most competitive and resource efficient system. Actual Yield Loss and Intercropping Advantage indices indicated reduction in yield of crops as compared to sole but it was compensated by (intercropping) production of two crops from same piece of land simultaneously. Sorghum-mungbean intercropping system produced wheat (2424 kg ha^{-1}) at par with other systems implying this system as most productive in terms of total production per unit area per unit time (one year rotation). The partial budget analysis revealed sorghum/mungbean-wheat as most profitable cropping system and Hydrogel as most profitable soil additive. Whereas the hydrogel was most profitable soil additive in all cropping systems except mungbean-wheat system where compost was found most profitable.

Chapter 1

INTRODUCTION

Out of total area of 79.61 million hectares, 20.43 million hectares are cultivated in Pakistan, with 25 per cent area being rainfed facing multifarious problems like water scarcity, low soil fertility and erosion hazards etc (Chaudhry and Shafiq, 1986). The average annual rainfall varies from 125 mm to over 1000 mm in various parts of the country(Appendix 1). The distribution is of bimodal pattern, such that 70 % rainfall is received during summer in the form of torrential rainstorm and rest of the 30 % is received during winter interrupted by prolonged period of drought. The observed and projected rainfall statistic has indicated further decline in winter rainfall which may further reduce productivity of winter crops (Appendix 2). Though in many areas, total amount of rainfall is enough for the maturity of both winter and summer crops, but erratic and unequally distributed rains combined with uneven topography result in loss of major portion of rain water as run off and thus rendering it unavailable for the crops at the critical stages. It has been estimated that runoff losses amount to be about 6 million acre feet which can be utilized for enhancing agricultural productivity if properly conserved (Khan, 1984).

Wheat (*Triticumaestivum*L.) is grown over an area of about 8.2 million hectares in Pakistan. In the Punjab province, the area under this crop is over 6 million hectares out of which 10 % is rainfed. The national average yield of this crop is around 2.5 t ha^{-1} but average in rainfed areas is much lower (0.6 to 1.5 t ha^{-1})as depends on the time, intensity and spread of rainfall (Anonymous, 2004). Wheat is sown in relatively drier months of October and November in Pothwar tract of the provincetherefore; conservation of summer monsoon rains can boost wheat production in the subsequent season. Use of suitable soil additives for *in situ* moisture conservation with an appropriate choice of crop sequence can enhance water use efficiency. Growing cereal crops after oilseeds or grain legumes can improve yields of subsequent cereal crops (Kirkegaard*et al.,* 2004).

Sorghum (Sorghum bicolor L. Moench), a heat and drought tolerant C4 plant, is a widely consumed cereal staple in subtropical and semi-arid regions of Africa and Asia (Reddy et al. 2009). It is also an important forage crop of countries having warm climatic conditions (Zerbini and Thomas, 2003). It is a major source of food, feed, fiber, and fuel across a range of environments and production systems. Most sorghum spp. are tolerant to heat and drought and are especially important in arid regions. Thus, sorghum is the key for the sustenance of human and livestock populations in hot and dry areas of the world (Sharma et al., 2010). In Pothwar region of Punjab, sorghum is widely grown under rainfed conditions both for fodder and grain purposes since the monsoon provides plentiful precipitation over about ten weeks.

In conditions of limited water resources, cereal-legume intercropping plays an important role in subsistence food production in both developed and developing countries (Amanullah*et al.,* 2006; Egbe and Adeyemo, 2007). So, cereal and grain legume intercropping can be potential enterprise for both organic and conventional farmers (Prins and de Wit, 2005).

Soils of Pothwar tract have problems like uneven topography, erosion, nutrient deficiency and limited water availability for crops when it is needed. The rainfall is the only source of soil moisture for crops in most of the area. Hence, conservation of rain water is a key factor for the success of crops in these areas and thus the only way to bring changes in the livelihood of the resource poor of farmers.

In ancient times, soils were covered with crop residues and stubbles etc. for soil and water conservation. In many countries these methods are still practiced, although useful, yet these traditional methods do not provide complete solution. In modern agriculture, various types of organic and inorganic materials such as gypsum, farm yard manure, compost and green manuring etchave been tested for conservation of soil and water in rainfed areas. Synthetic gel-forming polymers can be used for improvement of water conservation in arid and semiarid areas where these materials can favourably modify soil water relationships especially water retention and transmission (Chaudhry, 1992).

The polymers were first used for soil and water conservation in 1950s, when different types of compounds (non cross linked acryl amide, vinyl alcohols, liquid plastic and rubber compounds) were used for stabilizing soil aggregates and control of water and wind erosion (Gardner *et al.,* 1985; Helalia and Letey, 1988). In 1960s the cross linked polymers were introduced in which the polymer matrix was chemically engineered to permit absorption of large amount of water and subsequent release. These synthetic chemicals enhanced crop production under rainfed conditions (Johnson, 1988).

Qemisoyl is a long lasting, water absorbent with ability to absorb and retain large amount of water along with nutrients for uptake of crops. 1 gram of Qemisoyl has the ability to absorb upto 500 ml of water. This polymer applied once remained functional for 4-7 years in the soil (Anonymous, 2002).

Addition of organic fertilizers improves soil structure, nutrient retention, aeration, soil water holding capacity and water infiltration (Deksissa*et al.*, 2008). Soil organic matter added though organic fertilizers has a strong, positive effect on water holding capacity, improvements in soil aggregation and structure (Sharif *et al.*, 2004).

Gypsum is also an important chemical which is reported to conserve soil moisture. Spreading gypsum at soil surface before monsoon rains increased water infiltration, retention and decreased runoff and erosion (Yu *et al.*, 2003; Rashid *et al.*, 2008).

In this particular study, the traditional cropping system i.e. Fallow-Wheat-Fallow-Wheat, was compared with the Mungbean-Wheat-Mungbean-Wheat, Sorghum-Wheat-Sorghum-Wheat, and Sorghum + Mungbean-Wheat-Sorghum + Mungbean-Wheat. These rotations were evaluated for two years. The economics of soil additives and cropping systems used was compared for the recommendations of best soil additive and rotation for the given rainfed area.

Keeping in view the above mentioned facts and their interplay, the proposed field studies were conducted to:

1. Test various soil additives for soil moisture retention under different cropping systems.
2. Find out an appropriate cropping system for efficient resource utilization and increased crop production per unit area per year.
3. Compare the profitability of different soil additives and different cropping systems.

Chapter 2

REVIEW OF LITERATURE

The important reports about the effect of various soil additives on soil moisture conservation and cereal-legume performance are as under:

2.1 SOIL ADDITIVES AND SOIL MOISTURE CONSERVATION

Crop yield could be improved under water limited environments by capturing every drop of rainfall to meet the goal of more crop per drop. This could be achieved by adopting specific crop and soil management practises such as soil additives (Kijne*et al.,* 2003). The soil additives hydrogel, FYM, compost and gypsum helped to increase water retention in the soilresultingin increased crop yields. Albaladejo*et al*. (2012) reported an increase in soil water holding capacity by soil additives such as hydrogel. Moreover, incorporation of soil additives in soil improves soil structure and makes soil as C sink rather than C source. However, under traditional cultivation methods, most of carbon is lost due to intensive tillage but by application of additives, organic carbon in soil increases significantly resulting to maximum availability of water (Ludwig *et al.,* 2010).

The crop growing in rainfed regions and agricultural production could be boosted by conserving soil water using soil additives like hydrogel. Meanwhile these hydrogels could be helpful to make water available for sustainable agriculture under rainfed regions (Johnson and Leah, 1990). The work of Huang and Petrovic, (1994) confirmed the use of super absorbent polymers to conserve soil water. The conservation of rainwater using additives could improve the crop status under rainfed regions. Zhang *et al*. (2007) who emphasized on the use of hydrogel to conserve soil water with integration of modern techniques to improve crop yield in rainfed areas. The positive effect of hydrogels to improve crop performance under dry conditions was reported by Keshavars*et al*. (2012). They concluded that application of super absorbent polymer resulted to increased WUE and highest conversion of drymatter to grain due to good translocation potential of crop because of availability of water even under water stress. Akhter *et al*. (2004) also reported that hydrogel boosted water holding capacity of the soil.

Effective use of available physical resources helps to have enhanced crop productivity under different cropping system (ACIAR, 2010). The physical resources include proper selection of crop and soil managements. The cropping system (CS) efficiency could be increased by the use of soil amendments or adopting suitable cropping system having additional crop in it (Wivstad*et al.*, 2008). Chen *et al*. (2010) depicted that increasing availability of soil water through various techniques could increase choice of crop selection for the rainfed farmers. The moisture contents present within the soil profile is the basic necessity for healthy plant establishment. Soil additives applied for summer season crops improved the water retention of the soil even after the crop. Hydrogel enhanced water holding capacity of the soil to a greater degree as compared to the other soil additives which ultimately increased grain yield of subsequent wheat crop.

The use of hydrogel resulted in increased crop yield due to escape of crop from water stress. Widiatuti,(2008) and Green, (2004) reported that hydrogels have potential to increase crop yield under arid conditions of world. The hydrogels have potential to absorbs water four hundred times greater than the weight they have as reported by Monnig, (2005). Meanwhile, Nazarli*et al*, (2010) were of the view that hydrogels reduces the irrigation number to 50% by retaining maximum water in the soil.

Sharma, (2004) in his findings concluded that hydrogels have potential to conserve soil water and crop establishment. El-Hady and Abo-Sedera (2006) reported that addition of hydrogel in the form of soil amendments resulted in increased water-holding capacity and increased availability of water to plants. Furthermore, this helps in the improvement of soil structure, reduced compaction and makes nutrients available to the crop (Hickman and Whitney, 1998). More availability of water and nutrients due to hydrogel resulted in higher number of plants, good crop establishment,better vegetative and reproductive growth of crop and highest yield (Allahdadi*et al*., 2005 and El-Hady*et al*., 2009). Zhang *et al*., (2007) also concluded that hydrogels have great potential to increase plant growth and production indirectly by storing soil water and reclamation of soil.Widiatuti (2008) and Green (2004) concluded that hydrogels have potential to increase crop yield under arid conditions of world. The hydrogels have potential to absorbs water four hundred times greater than the weight they have as reported by Monnig (2005).

Abedi-Koupai (2008) concluded that hydrogel could be good source to conserve soil water. Similarly hydrogel improves soil water holding capacity, minimizes evapotranspiration and allow plants to survive under water stress (Chirino*et al*., 2008). The benefit of hydrogels to improve soil water contents were also confirmed by Landis (2012) who concluded that hydrogel could be good source to mitigate dry seasons. Soil amendments in the form of hydrogels, FYM and tank soil improves the soil structure and makes the nutrients available resulted to good growth of plants. The availability of nutrients due to hydrogel was confirmed by Asghari*et al*., (2011) and Narjary*et al*., (2012) and they concluded that hydrogels have potential to improve soil structure and texture resulting to good infiltration rate and availability of nutrients.

The work of Huang and Petrovic, (1994) confirmed the use of super absorbent polymers to conserve soil water. Johnson and Leah (1990) concluded that hydrogel are good source to store water and have potential to improve rainfed agriculture. Meanwhile, Specht and Harvey-Jones (2000) reported that plant survival rate was high due to hydrogels as they can retain water more in soil compared to control treatments. Viero*et al*. (2000) concluded that crop growth and yield could be improved by the application of hydrogels as soil amendments. Abedi-Koupai and Sohrab (2004) was of the view that hydrogels have potentials to absorb maximum water and make that water available to plants to increase their yield.

Hydrogels were found to increases the field capacity of soil (Kos and Le tan, 2003). Koupai*et al*. (2008) in their results elaborated that hydrogels increase soil water contents and can result in the significant reduction in the water demand of crops by alternatives sources.Specht and Harvey-Jones (2000) reported that plant survival rate was high due to hydrogels as they can retain water more in soil compared to control treatments. Increased water content of soil was reported by Al-Sheik and Al-Darby (1996) due to application of hydrogels.

Keshavars*et al.* (2012) determined that application of super absorbent polymer resulted in increased WUE and highest conversion of drymatter to grain due to good translocation potential of crop.

Anabayan and Palaniappan (1991) studiedthe effect of application of organic manures and a hydrophilic polymer in combination with fertilizer application and inoculation on soil moisture content, growth and yield of rainfed sorghum. The results revealed that application of enriched farm yard manure with urea mixed either 24 hours before sowing or at the time of sowing produced the highest Leaf area index (LAI), Dry matter production (DMP) and grain yield. High soil moisture content was noticed due to incorporation of compost. The effects of different levels of locally prepared hydrogels on the soil moisture contents of the sandy loam and loam soils and on growth response of three plant species, viz. barley (*Hordeumvulgare* L.), wheat (*Triticumaestivum* L.) and chickpea (*Cicerarietinum* L.) were investigated by Akhter *et al*. (2004). They reported that the addition of 0.1, 0.2 and 0.3 per cent hydrogel increased the moisture retention (θ_r) at field capacity linearly (r =0.988) and thus the amount of plant available water significantly in both sandy loam and loam soils compared to the untreated soils.Seed germination of wheat and barley was not affected but seedling growth of both species was improved by the gel amendment. In loam soil, seed germination of chickpea was higher with 0.2% gel and seedling growth increased with increase in gel level compared with control conditions. The hydrogel amendment caused a delay by 4-5 days in wilting of seedlings grown in both soils compared with control conditions. It was effective in improving soil moisture availability and thus increased plant establishment.

Laboratory and green house studies conducted by Hayat and Ali (2004) to observe the absorption of water by synthetic polymer (aquasorb) and to investigate the effect of its application on moisture content, nutrient supply, physico-chemical properties of sandy loam soil and yield of tomato crop. They observed that moisture content in the polymer treated soil increased from 30 to 850%. Saturation percentage increased significantly and the response was 17% better than the control. Particle density and bulk density were reduced due to the application of polymer. There was 8% reduction in particle density of soil, whereas reduction in bulk density was 4 to 80%. The pH and electrical conductivity of the soil remained unaffected. Vegetative growth and fruit production of tomato crop were significantly increased. The effect of soil additives (ploymers) on moisture conservation, soil properties and crop yield was also investigated by Hayat and Chaudhry (2001). It was revealed that soil moisture content in the polymer treated soil varied from 2-9 times compared with those of untreated soils. Saturation percentage increased from 30 (control) to 38 per cent (1.50 per cent aquasorb) and particle density and bulk density were reduced from 2.63 to 2.50 and 1.50 to 1.06 per cent, respectively due to the application of aquasorb, whereas pH and electrical conductivity of the soil remained unaffected. Vegetative growth and fruit production of tomatoes were significantly increased.

The role of gypsum in moisture conservation and crop yield enhancement of subsequent crop was extensively studied by Rashid *et al.* (2008) in semi-arid areas of northern Punjab. It was reported that gypsum improved the grain yield of wheat up to 46 % due to increased moisture contents in soil profile at sowing of wheat. Gypsum application was found to double the final infiltration rates as compared to polyacrylamides (Yu *et al.*, 2003).

The comparative study of El-Hady and Camilia (2006) on conditioning effect of hydrogels when mixed with organic composts on the growth response, production, nutrients uptake and water and fertilizers use efficiency by the plants. The treatments they studied were:- untreated soil, soil treated with 1 and 2 kg compost (OM)/plant pit, , soil treated with 2g and 4g mixture of anionic and cationic polyacrylamide hydrogels (G)/plant pit and soil treated with 1 kg OM +1g G; 1kg OM+2g G, 2kg OM+ 1g G and 2 kg OM+ 2 g G/plant pit, respectively. They observed that the conditioners significantly increased the fresh and the dry weights; N, P and K uptake, marketable yield and water and fertilizers use efficiency of the plants. They concluded that applying 1 kg OM + 2g G to the plant pit was most suitable to get benefits of both types of soil conditioners without adverse effects on the production.

2.2 SOIL ADDITIVES AND LEGUME-CEREAL PERFORMANCE

Water storage in the soil is serious issue of world and its increasing day by day due to extensive agriculture. It is necessary to use such type of system which can sustain the available natural resources on long time span. The earlier researcher in their findings concluded that water use efficiency could be improved by modifying existing cropping system compared to traditional one (Connor, 2004; Ma *et al*., 2008). More crop per drop the famous slogan by Kijne*et al*. (2003) could only be achieved by conserving soil water under rainfed agriculture which is possible by modification in the cropping system and use of hydrogels. Similarly, by adopting such techniques might resulted to reduction in the water loss due to transpiration as earlier it was reported that up to 40% of the total available soil water was found to be lost by soil evaporation in wheat in Australia (Siddique *et al*., 1990).

Connor (2004) in their findings concluded that efficiency of system could be increased by modifying cropping system. The use of additive crop like Mungbean resulted to conservation of soil water and nutrients. Cropping system involving mungbean has been found to perform better with little or no competition for resources (Hauggaard-Nielsen and Jensen, 2001; Zhang and Li, 2003). Andersen *et al*. (2007) in their results concluded that intercropping is better than sole cropping as it helps in the utilization of resources effectively. Inclusion of legume crop like mungbean in the system might result to increased N contents of soil which might increases yield of intercropped crop like sorghum. However, Kirkegaard*et al*. (2008) concluded that intercropping with legumes resulted in better crop growth compared to monoculture.

Malai and Muthasankaranarayanan (1999) stated that sorghum yield remained high under sole compared to intercropping. The results were also in relevant to the conclusion of Rashid *et al*. (2004) who reported highest grain yield of sorghum when planted sole compared to intercropping. The interactive effect of cropping system and soil additives revealed that additives performance was better under sole cropping. This might be due to good water absorption potential of additives and its availability to crop at the time of need. The use of soil additives like crop residuals, mulch plants, waste, litter, straw, stubble, gypsum, compost, FYM and hydrogel have been proved earlier as potential source to conserve soil water and increase crop growth and yield (Silberbush*et al*., 1993).

The efficiency of the system could also be improved by diagnosing the defects in the existing cropping system and replacing that defects with new systems to utilize resources effectively (Dore et al., 2008 and Wivstad*et al*., 2008). The Mungbean-Wheat system could be an alternative to Fallow-Wheat cropping system under rainfed conditions. The results of earlier researcher depicted that availability of water could increase choice of selection of crops for the rainfed farmers (Chen *et al*., 2010). Similarly, inclusion of legume crop like mungbean in the system might result to increased N contents of soil which might increases yield of coming wheat crop compared to other cropping patterns. Similar results were reported by earlier researcher about increased yield and N due to grain legumes system compared to monoculture where cereal was planted only (Kirkegaard*et al*. 2008). The 49% increased wheat crop yield in Australia due to inclusion of legumes in cropping patterns reported by Evans *et al*. (2003) which might be due to increased N in soil. However, Peoples and Craswell (1992) concluded 37% increased wheat crop yield due to use of legume in cropping patterns. Meanwhile, Angus *et al*., 2001 in their findings concluded that yield might increases to 40-50% due to inclusion of grain legumes in the cropping patterns even if N application is limited. However, Stevenson and van

Kessel (1996) reported 91 % increased wheat yield when pea was used as legume crops in cropping system.

The negative impacts of exhaustive crops like sorghum and maize was reported by earlier researcher who concluded that crops planted before wheat have impacts on water in arid environments as recharge might not occur due to these crops in summer and which might affect the growth of wheat or other crops like Gram and Canola significantly (Norwood, 2000). Therefore, they suggested removing fallow-wheat system and they suggested use of such crops which are not exhaustive in nature (Miller *et al.,* 2002; Gan*et al.,* 2003).

Water scarcity is main concerned of rainfed agriculture. However, this issue could be solved by using soil additives which can conserve soil water and increased crop yield. The use of soil additives as soil conditioners was earlier reported by Shainberg*et al*. (1990) who concluded improved soil structure due to use of soil conditioners. Yangyuoru*et al*. (2006) reported increased water storage due to use of soil additives while El-Hady*et al*. (2009) concluded that soil additives increases water availability to the crops.

The use of hydrogel could improve water availability to the crops by increasing the retention pores and decreasing drainage pores even under sandy soils as concluded by El-Hady and Abo-Sedera(2006). Similar results were observed by Leciejewski (2009) and Paluszek and Zembrowski (2008) who concluded that hydrogel could be good option to increase soil water status and crop productivity. Similarly, water retention capacity of soil could also be increased by hydrogel application (Abedi-Koupai and Sohrab, 2004).

Viero*et al.* (2000) concluded that crop growth and yield could be improved by the application of hydrogels as soil amendments. Abedi-Koupai and Sohrab (2004) was of the view that hydrogels have potentials to absorb maximum water and make that water available to plants to increase their growth and developments. Dehgan*et al.* (1994) concluded that hydrogels is good option to grow plant under water limited conditions. They concluded that hydrogels enhances drought tolerance of crop under water stress resulted to highest thousand grain weight compared to control treatments.

The effect of cropping sequenceand residue management on crop production were studied by Taa*et al.* (2004). The results revealed that that cropping system had significant effect on wheat grain yield. It was also noticed that Fababean-wheat-wheat or Fababean-wheat treatments were superior to continuous wheat. Kihanda*et al.* (2007) evaluated the sustainability of cereal/legume intercropping by monitoring trends in cereal or legume grain yield and soil extractable P (Olsen method) in semi-arid Eastern, Kenya. Goat manure was applied annually for 13 years at 0, 5 and 10 t ha^{-1}. The trends in grain yields were not identifiable because of season-to-season variations. Olsen P increased for the first seven years of manure application and then remained constant. The residual effect of manure applied for four years only lasted another seven to eight years when assessed by yield, SOC and Olsen P. Mineral fertilizers provided the same annual rates of N and P as in 5 t ha^{-1}manure and initially gave the same yield as manure, declining after nine years to about 80%. It was concluded that manure applications could be made intermittently and nutrient requirements topped-up with fertilizers.

Field experiments by Rana*et al*. (2006) studied the relative moisture utilization by maize (*Zea mays* L.) grown in a mixed or in a sole situation. The maize equivalent was higher in maize paired row (40/80 cm) + 2 rows of mungbean (*Phaseolusradiata* L.) than the sole maize crop. An increase in water-use efficiency (WUE) was observed in intercropping systems. The water-use efficiency was the highest (10.14 maize equivalent use ha^{-1} mm^{-1}) in maize paired row (40/80 cm) + 2 rows of mungbean. Growth, yield attributes and yield as well as maize equivalent was significantly improved with farmyard manure (FYM) + dust mulch + straw mulch treatment over no mulch. Among the moisture-conservation practices, higher WUE was recorded under FYM + dust mulch + straw mulch, closely followed by Kaolin + dust mulch + straw mulch.

2.3 CEREAL-LEGUME INTERCROPPING AND COMPETITIVE INDICES

Land Equivalent Ratio (LER) judge the performance of land used for intercropping in comparison to sole cropping. It is useful tool to check productivity advantage of field under multiple conditions. The benefits of LER were studied by Mead and Willy (1980). They reported that higher land area required for sole crop cropping pattern compared to inter-crop cropping system. Similarly, work of Aal(1991) and Saeed *et al.* (1999) confirmed highest LER for intercropping compared to mono-cropping. Meanwhile, Bismillah*et al*. (2001) concluded that comparative benefits between two cropping system could be depicted by LER. The positive inter-specific interference of crops in the intercropping could be checked by value of LER and if value of LER becomes higher than 1.0 it indicates the intensive influence of intercropping. Similar conclusions were drawn by Dariush*et al.* (2006) while Kutrata (1986) was of the view that an LER=1 indicates no difference between intercrop and monocultures crop yield while if LER>1 confirms the advantage of intercrop compared to monoculture. Meanwhile he elaborated that if LER is 1.2 than it depicted 20% greater area requirements by sole cropping compared to intercropping to have same yield. Kebebew (2014) evaluated intercropping effect on yield components of intercrop crops compared to sole cropping and concluded that LER remained highest for intercropping compared to mono-cropping. He further confirmed that productivity of intercropping could be easily evaluated by LER.

The efficiency and financial benefits of systems like intercropping could be easily depicted by different competition functions which includes relative crowding coefficient (Dhima*et al.,* 2007). The system efficiency might be evaluated by relative crowding co-efficient (RCC) and other efficiencies indicators (Saba *et al*., 2008). Evaluation of vetch–cereal mixtures using RCC and other intercropping indices like aggressivity (A), actual yield loss (AYL), monetary advantage index (MAI), and intercropping advantage (IA) was done by Dhima*et al. (*2007). They concluded that LER and K values remained highest in intercropping compared to sole cropping showing, maximum potential of intercropping to exploit available resources in optimum way. The benefits of intercropping were evaluated by Ghosh (2004) who studied intercropping legumes with non-legumes crops in the semi-arid region. They concluded that competition and economics of legume based intercropping system remained highest compared to monocropping. Since efficiency of system could easily be checked by land equivalent ratio (LER) and relative crowding coefficient (RCC) therefore in their findings they recorded highest LER and RCC for intercropping compared to sole cropping.

Comparison of intercropping with sole crop was done by Yilmaz *et al*. (2008). Their work concluded that different planting patterns like intercropping and sole cropping could be easily evaluated by indices like aggressivity. Ghosh (2004) and Dhima*et al*. (2007) concluded that cereal crops have positive aggressivity compared to legume crops which was because of exhaustive potential of cereals like sorghum. The use of indices like aggressivity, land equivalent ratio, relative crowding coefficient, competitive ratio, actual yield loss, monetary advantage, and intercropping advantage might be recommended for evaluation between sole and intercropping as concluded by Agegnehu*et al*. (2006) and Banik*et al*. (2006).

Bhatti *et al*. (2006) in their findings depicted that competitive behaviour of components crops in different systems could easily be evaluated by higher values of relative crowding coefficient, competitive ratio and positive sign of the aggressivity. The advantage of use of different competitive indices to check competition among different components was reported by different scientists in their findings (Sarkar and Chakraborty, 2000; Sarkar and Sanyl, 2000; Sarkar*et al*., 2001). Saban *et al*. (2008) reported that yield loss of legumes under intercropping system was due to competition for light and resources. The competition between and within component crops and species behaviour could be best depicted by actual yield loss (AYL) (Banik*et al*., 2000).

Intercropping Advantage (IA) is best indicator to check the economic feasibility of intercropping system as concluded by Banik*et al*. (2000). The IA depicted less yield loss for one crop compared to other and use of IA as important economic parameter was also confirmed in the findings of Yilmaz *et al*. (2008).

2.4 SOIL ADDITIVES, INTER-CROPPING AND SUBSEQUENT WHEAT CROP

Wheat is main crop cultivated largely in different parts of world and its yield is under severe threat due to deficiency in soil water (Emam*et al*, 2007). Drought stress is main concern for rainfed agriculture and it reduces crop yield potential significantly as concluded by Martinez (2007). Since grain yield of wheat is outcome of interactive effect of yield components like number of tillers, spikelets per spike, grains per spike and thousand grain weight (Dencic, 2000).

The highest biological yield of Rabi crop (wheat) after legume might be due to fact that legume can fix atmosphere nitrogen effectively which may ultimately improves soil nutrient status resulting to good growth of crops. Meanwhile, earlier researcher in their findings reported that wheat yield increases significantly due to sowing of legume crops in the cropping pattern (Gan*et al.*, 2003). They further concluded that increase yield might be due to residual nitrogen and soil water prior to sowing of crop due to previous legume crop. Similarly, Norwood (2000) concluded in their findings that winter yield remained highest when planted after legume crops compared to fallowing. Robertson *et al.* (2010) in their findings concluded that rotations with legume crops could be an option for enhanced crop biomass and productivity with good economic returns. The synergistic effect of following crops was earlier reported by Anderson (2005) who concluded that yield of wheat crop increased due to synergistic effect of crops on crop establishment parameters like germination percentage which resulted to highest yield similar to our findings. Meanwhile increased wheat yield due to break crop system compared to continuous wheat cropping system was reported by Kirkegaard*et al*. (2008) who concluded highest wheat yield due to residual fertility (N and P) and greater available soil water at planting following the break crop than following a previous wheat crop. The effect of previous crops on water availability for next crops resulted to highest germination percentage was also reported by Hatfield *et al*. (2001). They further elaborated that crop residues due to previous crops might resulted to differences in soil water contents at planting of crops like wheat which might result to highest germination percentage. The findings of Unger and Vigil (1998) and Gregory *et al*. (2005) concluded that suitable cropping patterns could maintain soil water by increased organic matter content, improved soil structure and water holding capacity. Soil additives also increased moisture contents of the soil.

The additive effect of legume crop resulted to good crop growth and development. Struik and Bonciarelli(1997) concluded that cropping system with legume could maximize the beneficial processes like nitrogen fixation resulted to increased availability of nutrients. Meanwhile, sustainable cropping patterns resulted to improvement in the soil structure and good establishment of crop. Similarly, Van Ittersum and Rabbinge (1997) were of the view that cropping system should be environmental friendly as it might results to overall recycling of all essential nutrients in the soil. Wu(2008) and Ma *et al.* (2008) in their findings concluded that increased water use efficiency and yield could be achieved by transition in the cropping system from Fallow to legume base. The legume based cropping system resulted to higher recharge of water due to increased infiltration and drainage as concluded by O'Connell *et al.* (2003). Similar conclusion was also made by Farahani*et al.* (1998) who depicted that legume in the cropping system resulted to higher water availability in the soil and good crop yield. Liu *et al.* (2009) found increased wheat yield due to sustainable cropping system like induction of legumes with main crops like wheat.

In the light of the fact that water is the most critical factor for crop productivity and is usually scarce in the Potowar region, the farmers of the area need a technology that can rescue their crops at the time of water stress. The literature shows that the soil additives like Qemisoyl, Gypsum, Compost and Organic matter has the potential to retain water in the root zone and release it when required by the crops. However, very little work for this tract has been reported on the subject that needs to be tested in the prevailing conditions. Similarly intercropping is not common on the farmers' field, as research is lacking on this technique for the Potowar area. To test various soil additives for soil moisture retention under different cropping systems a study was conducted in the region with the methodology given in the next chapter.

Chapter 3

MATERIALS AND METHODS

The research studies comprised of lab and field experiments. The brief description is given below:

3.1 SCREENING OF SOIL ADDITIVES FOR SOIL MOISTURE CONSERVATION

The study involved evaluation of various soil additives in water as well as soil media in the laboratory to determine their ability for absorption and retention of water. This enabled us to quantify the comparative ability of soil additives for water absorption and retention in both the media. The combinations of soil additives showing maximum absorption and retention were carried to the field for further testing. The experiment involved following possible combinations of soil additives.

3.1.1 Treatments

1. Control (without any additive)
2. Qemisoyl @ 15 kg ha^{-1}
3. Farm Yard Manure (FYM) @ 25 Mg ha^{-1}
4. Compost @ 0.75 Mg ha^{-1}
5. Gypsum @ 2.5 Mg ha^{-1}
6. Qemisoyl @ 15 kg ha^{-1} + FYM @ 25 Mg ha^{-1}
7. Qemisoyl @ 15 kg ha^{-1} + Compost @ 0.75 Mg ha^{-1}
8. Qemisoyl @ 15 kg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}

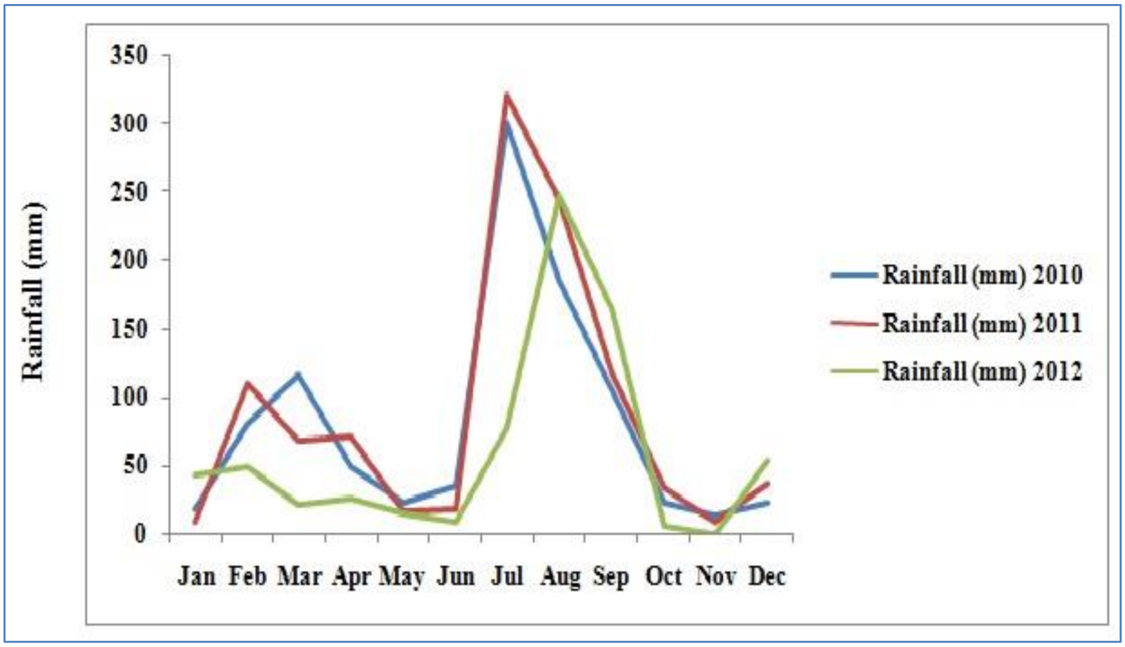
9. FYM @ 25 Mg ha^{-1} + Compost @ 0.75 Mg ha^{-1}
10. FYM @ 25 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}
11. Compost @ 0.75 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}
12. Qemisoyl @ 15 kg ha^{-1} + FYM @ 25 Mg ha^{-1} + Compost @ 0.75 Mg ha^{-1}
13. Qemisoyl @ 15 kg ha^{-1} + FYM @ 25 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}
14. Qemisoyl @ 15 kg ha^{-1} + Compost @ 0.75 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}
15. FYM @ 25 Mg ha^{-1} + Compost @ 0.75 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}
16. Qemisoyl @ 15 kg ha^{-1} + FYM @ 25 Mg ha^{-1} + Compost @ 0.75 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}

Qemisoyl was obtained from Siddique Engineering Gulberg Lahore, Pakistan. The water absorption and retention properties of different soil additives were measured using Pressure Membrane Apparatus. The soil samples were applied with pressures of 0.33, 1, 3, 7 and 15 bars. Pressure plates were saturated in water over night and then used in apparatus. Required pressure was applied for 48 hours to maintain equilibrium. The moisture contents of the soil cores were measured gravimetrically. RETC-Fit software was used to simulate the moisture characteristic curves (Reeve and Carter, 1991).

3.2 FIELD TRIALS

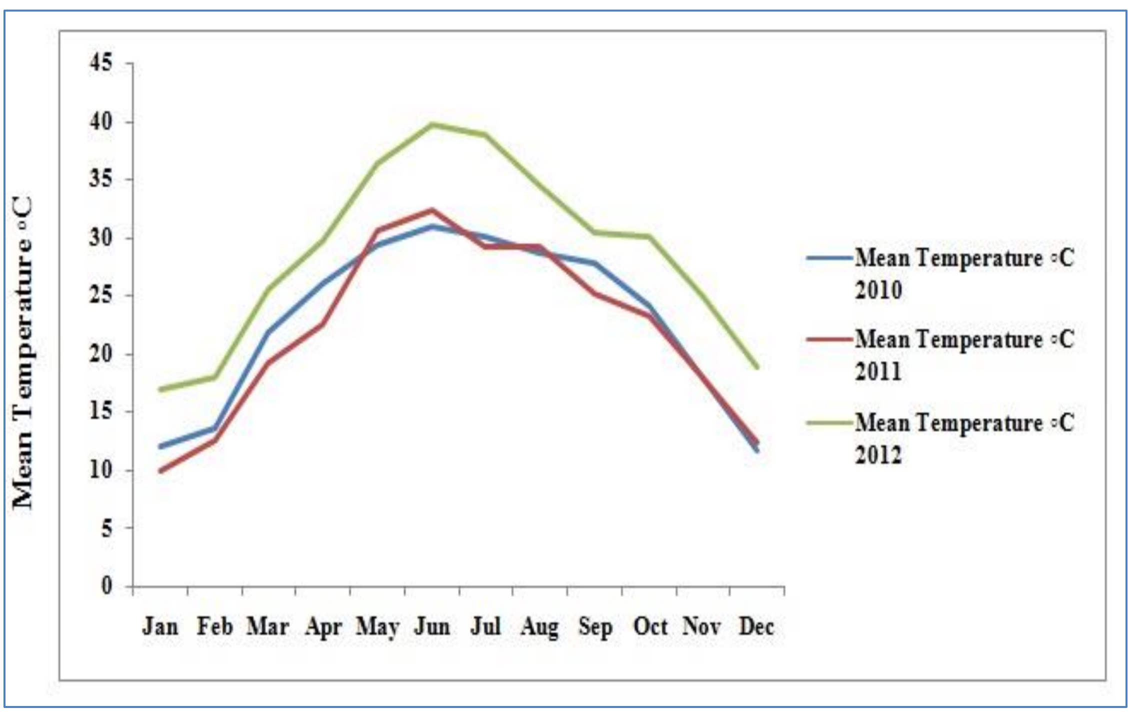
Field experiment was carried out under rainfed conditions in the experimental area of PMAS, Arid Agriculture University Rawalpindi (Fig 3.1) during 2010-11 and 2011-12. The meteorological parameters for study site are presented in Fig 3.2 (a, b).

Fig 3.1Geographical location of the study site in the research area of PMAS-Arid Agriculture University, Rawalpindi, Pakistan



Source: Pakistan Agro-metrological Station Rawalpindi

Fig 3.2 (a) Rainfall during the study period



Source: Pakistan Agro-metrological Station Rawalpindi

Fig 3.2 (b)Mean temperatures during the study period

The selected additives from the laboratory experiment were tested in the field conditions for their role in moisture conservation and ultimate effects on legume-cereal performance. In laboratory studies all the additives were mixed with soil and mix with water till saturation. However in field studies the same were tilled into the soil. It is further added that the additives were applied once and studied their effects for two years. The Qemisoyl is reported to be effective for 4-7 years and then degraded and disappeared. Sorghum variety JS-263 (Fodder Research Institute, Sargodha) and mungbean cultivar NM-2006 (Nuclear Institute for Agriculture and Biology, Faisalabad) were used as medium of research. Compost was obtained from Lahore Compost (Composition: Organic Matter: 25% (Approx.) Macro Nutrients: Nitrogen (N): 1.5%-2.5%, Phosphorus (P): 1%, Potash (K): 1%, Micro Nutrients: Zinc: 253 ppb, Ferrous 388 ppb, Maganese 18 ppb, Copper 255 ppb, Magnesium 3.9 ppm, Sodium 3.9 ppm). The field experiment was laid out in RCBD design with split-plot arrangement of treatments. Cropping systems were allocated to main plot whereas soil additives in subplots. Main plot size was kept as 4.2 m x 19.0 m and subplot 3.0 m x 4.2 m.

3.2.1 Treatments

A. Cropping Systems:

CS1: Summer Fallow-wheat

CS2: Mungbean-wheat

CS3: Sorghum- wheat

CS4: Sorghum + mungbean- wheat

B. Soil Additives:

SA1: Control

SA2: Qemisoyl @15 kg ha^{-1}(0.015 Mg ha^{-1})

SA3: Farm Yard Manure @ 25 Mg ha^{-1}

SA4: Compost @ 0.75 Mg ha^{-1}

SA5: Gypsum @ 2.5 Mg ha^{-1}

During summer 2010and 2011, sorghum and mungbean (green gram) were intercropped together and planted separately as well, while wheat crop followed in winter. Sorghum was planted with the help of manual drill keeping inter-plant spacing of 15 cm and inter-row spacing of 60 cm using seed rate 20 kg ha^{-1}. The seeds of mungbean were drilled @ 25 kg ha^{-1} with an inter-plant x inter-row spacing of 10 x 30 cm, respectively. In case of intercropping one row of mungbean was sown between the two rows of sorghum. The fertilizer was also applied to sorghum and mungbean at recommended rates i.e. 80-55-00 and 22-55-00 kg N-P-K per hectare, respectively at the time of sowing. Sorghum and mungbean were harvested at maturity. After harvesting, wheat was sown on same experimental site. Two weeks before summer sowing(1^{st} year), various soil additives i.e. farm yard manure @ 25 Mg ha^{-1}, gypsum 2.5 Mg ha^{-1}, compost @ 0.75 Mg ha^{-1} and Qemisoyl 0.015 Mg ha^{-1}wereapplied (Fig 3.3).

During subsequent winter seasons (2010-11 & 2011-12) wheat crops was sown using recommended seed rates of 100 Kg ha^{-1}. Fertilizer was applied as basal dose @ 90-60-60 Kg N-P-K per hectare. Soil additives were applied once during the experimental cycle before monsoon rains in summer 2010 and their affects were studied during two subsequent years. Field ridges across experimental plots were ensured to restrict the movement of rainwater from adjacent areas.

<table>
<tr><td rowspan="7">R1</td><td rowspan="2"></td><td colspan="4">Cropping Systems (CS)</td></tr>
<tr><td>CS3</td><td>CS1</td><td>CS4</td><td>CS2</td></tr>
<tr><td rowspan="5">Soil Additives (SA)</td><td>SA3</td><td>SA5</td><td>SA1</td><td>SA2</td></tr>
<tr><td>SA1</td><td>SA2</td><td>SA3</td><td>SA4</td></tr>
<tr><td>SA5</td><td>SA3</td><td>SA4</td><td>SA1</td></tr>
<tr><td>SA2</td><td>SA4</td><td>SA5</td><td>SA5</td></tr>
<tr><td>SA4</td><td>SA1</td><td>SA2</td><td>SA3</td></tr>
<tr><td rowspan="7">R2</td><td rowspan="2"></td><td colspan="4">Cropping Systems (CS)</td></tr>
<tr><td>CS4</td><td>CS2</td><td>CS1</td><td>CS3</td></tr>
<tr><td rowspan="5">Soil Additives (SA)</td><td>SA1</td><td>SA2</td><td>SA5</td><td>SA3</td></tr>
<tr><td>SA3</td><td>SA4</td><td>SA2</td><td>SA1</td></tr>
<tr><td>SA4</td><td>SA1</td><td>SA3</td><td>SA5</td></tr>
<tr><td>SA5</td><td>SA5</td><td>SA4</td><td>SA2</td></tr>
<tr><td>SA2</td><td>SA3</td><td>SA1</td><td>SA4</td></tr>
<tr><td rowspan="7">R3</td><td rowspan="2"></td><td colspan="4">Cropping Systems (CS)</td></tr>
<tr><td>CS1</td><td>CS3</td><td>CS4</td><td>CS2</td></tr>
<tr><td rowspan="5">Soil Additives (SA)</td><td>SA5</td><td>SA3</td><td>SA1</td><td>SA2</td></tr>
<tr><td>SA2</td><td>SA1</td><td>SA3</td><td>SA4</td></tr>
<tr><td>SA3</td><td>SA5</td><td>SA4</td><td>SA1</td></tr>
<tr><td>SA4</td><td>SA2</td><td>SA5</td><td>SA5</td></tr>
<tr><td>SA1</td><td>SA4</td><td>SA2</td><td>SA3</td></tr>
</table>

Fig 3.3 Layout of Field Trial

3.3 DATA COLLECTION

3.3.1. Agronomic Parameters

Data on following parameters were recorded for sorghum, mungbean (green gram) and wheat as per standard procedures:

3.3.1.1 Plant height (cm)

Ten plants were selected randomly from each experimental plot. Height of each was measured using meter rod. The mean height was recorded in centimeters.

3.3.1.2 No. of plants m^{-2}

Two quadrates in each experimental unit were sampled for recording number of plants per unit area.

3.3.1.3 Thousand grain weight (g)

Two samples were taken at random from the seed lot in each experimental unit. Weight of 1000 seeds was recorded using seed counter and digital balance.

3.3.1.4 Biological yield (Kg ha^{-1})

For biological yield the above ground part of the each crop from 1m x 1m area was manually harvested from each experimental treatment at the time of maturity.The weight of samples was recorded after sun-drying of all plants using electronic digital hanging balance.

3.3.1.5 Grain yield (Kg ha^{-1})

Fig 3.4 Application of soil additives before rainy season in pre-laid out experimental field at research area of PMAS-Arid Agriculture University, Rawalpindi, Pakistan

Fig 3.5 Filed trial observation by Muhammad Sohail-ur-Raza at research area of PMAS-Arid Agriculture University, Rawalpindi, Pakistan

The above sun-dried samples were threshed to record weight of grains. The data was expressed as grain yield (kg ha^{-1}).

3.3.1.6 Harvest index (%)

Harvest index for various experimental treatments was determined using following method:

$$HI = \frac{\text{Grain Yield}}{\text{Biological Yield}} \times 100$$

Other yield components specific to each of the experimental crop were also recorded during the course of experimentation. These are listed below:

3.3.2 MUNGBEAN

3.3.2.1 No. of branches plant^{-1}

3.3.2.2 No. of pods plant^{-1}

3.3.2.3 No. of seeds pod^{-1}

3.3.3SORGHUM

3.3.3.1 Panicle length

3.3.3.2 No. of panicles m^{-2}

3.3.4 WHEAT

3.3.4.1 No. of tillers plant^{-1}

3.3.4.2 Spike length

3.3.4.3 No. of grains spike^{-1}

Ten plants were randomly selected from each treatment at crop harvest and were used to measure above parameters.

3.4 GROWTH AND PHYSIOLOGICAL PARAMETERS

3.4.1 Crop Growth Rate (CGR)

The parameter for all the test crops was calculated by the formula given by Radford (1967):

$$CGR = \frac{W_2 - W_1}{t_2 - t_1}$$

Where

W_1 = Dry weight of crop at 1st sampling

W_2 = Dry weight of crop at 2nd sampling

$t_2 - t_1$ = Time duration between two successive samplings

3.4.2 Leaf Area Index (LAI)

The LAI was calculated adopting methodology proposed by Gardner *et al.* (1985):

$$LAI = \frac{\text{Leaf area}}{\text{Ground area}}$$

Ten plants were selected at random to measure leaf area index. Leaf area was measured using leaf area meter.

3.4.3 Leaf Area Duration (LAD)

The LAD was determined using formula proposed by Hunt (1978):

$$LAD = (LAI_2 + LAI_1) \times \frac{t_2 - t_1}{2}$$

Where:

LAI_1 = The index value at 1st sampling.

LAI_2 = The index value at 2nd sampling. .

$t_2 - t_1$ = Time duration (days) between two successive samplings

3.4.4 Net Assimilation Rate (NAR)

The NAR was determined using formula as proposed by Gardner *et al.*(1985):

$$NAR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\ln LAI_2 - \ln LAI_1}{LAI_2 - LAI_1}$$

Where:

In = Natural logarithm

Other terms in the formula are explained above.

3.4.5 Photosynthetic Rate/ Transpiration Rate/Stomatal Conductance

The physiological parameters (photosynthetic rate, transpiration rate and stomatal conductance) for sorghum and wheat were measured at maximum leaf area growth stage by Infrared Gas Analyzer (IRGA) given by Long and Bernacchi (2003). The IRGA shines infrared light through a gas sample onto a detector. CO_2 in the sample absorbs energy, so the reduction in the level of energy that reaches the detector indicates the CO_2 concentration. Modern IRGAs take account of the fact that H_2O absorbs energy at similar wavelengths as CO_2. Modern IRGAs may either dry the gas sample to a constant water content or incorporate both a CO_2 and a water vapour IRGA to assess the difference in CO_2 and water vapour concentrations in air between the chamber entrance and outlet. During the shiny mid-day, the full leaf was placed in the incepted portion of IRGA for few seconds and the reading for all the desired physiological parameters appeared on the screen of the machine. However, for mungbean, the procedure adopted by Kubota and Hamid (1992) was followed to measure the above parameters. The data on physiological parameters for sorghum, wheat was recorded at Z41 (Flag leaf sheath extending stage) while for mungbeanrecorded at S5 (Peak vegetative growth stage) following methodology adopted by Zadoks *et al.* (1974), Vanderlip (1993) and, Kubota& Hamid (1992), respectively.

3.5 COMPETITIVE INDICES

Following competitive indices were calculated to determine resource use efficiency and competitiveness of intercropping system.

3.5.1 Land Equivalent Ratio (LER)

The equivalent ratio were calculated as proposed by Mead and Willey (1980):

$$LER = LER_s + LER_m$$

$$LER_s = Y_{si}/Y_s$$

$$LER_m = Y_{mi}/Y_m$$

Where:

Y_s and Y_m represent sorghum and mungbean crop yields in monocrop fashion respectively, whereas, Y_{si} and Y_{mi} are yield of sorghum and mungbean intercrops respectively.

3.5.2 Relative Crowding Coefficient (RCC)

The Relative Crowding Coefficient (K) is a measure of the relative dominance of one species over the other in a mixture (Ghosh, 2004). The K was calculated as:

$$K = K_s \times K_m$$

$$K_s = \frac{Y_{si} \times Z_{mi}}{(Y_s - Y_{si}) \times Z_{si}}$$

$$K_m = \frac{Y_{mi} \times Z_{si}}{(Y_m - Y_{mi}) \times Z_{mi}}$$

Where:

Z_{si} represent sown proportion of the sorghum crop in mixture with Mungbean and Z_{mi} represents sown proportion of mungbean in mixture with sorghum. When K>1, the species in more competitive, when K=1, there is no competition and, when K<1, the species is less competitive with low resource use efficiency and higher yield loss.

3.5.3 Aggressivity (A)

The aggressivity (A) shows change in the relative yields of crops in intercropping (Agegnehu*et al.*, 2006). It was calculated using following formula:

$$A_s = \frac{Y_{si}}{Y_s \times Z_{si}} - \frac{Y_{mi}}{Y_m \times Z_{mi}}$$

$$A_m = \frac{Y_{mi}}{Y_m \times Z_{mi}} - \frac{Y_{si}}{Y_s \times Z_{si}}$$

When $A_s$is zero, it means both the crops are competitive equally

When $A_s$is positive for a crop, it means the crop is more aggressive or domiant over ther other, and vice versa.

3.5.4 Competitive Ratio (CR)

The CR is another measure to express competitiveness of species in an intercropping system. It was considered more useful measures than relative crowding coefficient and actual yield loss (Dhima*et al.*, 2007). The CR was calculated using the following formula:

$$CR_s = \frac{LER_s}{LER_m} \times \frac{Z_{mi}}{Z_{si}}$$

$$CR_m = \frac{LER_m}{LER_s} \times \frac{Z_{si}}{Z_{mi}}$$

3.5.5Actual Yield Loss (AYL)

It gives more precise evidence regarding inter and intra-species competition as compared to other competitive indices. It also represents the performance of each of the species in an inter-cropping system (Banik*et al*., 2000). The index was calculated using following formula:

$$AYL = AYL_s + AYL_m$$

$$AYL_s = [((Y_{si} / Z_{si}) / (Y_s / Z_s)) - 1], \text{ and}$$

$$AYL_m = [((Y_{mi} / Z_{mi}) / (Y_m / Z_m)) - 1]$$

3.5.6 Intercropping Advantage (IA)

Intercropping advantage is another useful index to represent competitive of the species. It was determined using formula proposed by Banik*et al*. (2000) and Dhima*et al*. (2007): .

$$IA_s = (AYL_s) \times (P_s)$$

$$IA_m = (AYL_m) \times (P_m)$$

Where,

P_s is the commercial value of sorghum and P_m is the commercial value of Mungbean (intercrop).

3.6 PHYSICO-CHEMICAL PROPERTIES OF SOIL

Soil sampling was done (0-15 cm) before application of soil additives to characterize the experimental soil. The soil analysis of the experimental soil showed its texture as loam with pH of 8.1, EC (0.20-0.24 dS m^{-1}), while available phosphorus 3.64 mg kg-1 (Table 3.1). Analysis was done at Laboratory # 2 Department of Soil and Water Conservation, PMAS-AAUR.

3.6.1 Soil Moisture Content

The soil sampling was done using king tube (a soil-sampling tube, core barrel, or drive sampler used to take soil samples for determination of soil moisture) up to 90 cm depth. The core was divided into three samples of 30 cm incremental depth (0-30, 30-60 and 60-90 cm). The soil moisture sampling was before sowing and after harvest of each summer and winter crop with the assumption that no water came in and out of the research area except the rainwater received.

Moisture contents were determined by gravimetric methods (Hesse, 1971) for which soil samples were collected in the pre-weighed metallic cans and weighed. The samples were oven-dried at 105 ^{o}C for 48 hours, after which oven-dry weight of samples were recorded. Moisture in the collected samples was calculated as under:

$$\text{Soil moisture} = \frac{W_f - W_o}{W_o} \times 100$$

Wf represents the fresh/initial weight of soil sample

Wo represents the oven-dried weight of soil sample

Table 3.1 Physico-Chemical characteristics of the study soil

Soil Characteristic	Units	Values
Texture		Loam
pH	-	8.1
Electrical Conductivity	dS m^{-1}	0.24
Organic matter	%	0.53
Phosphorus **(available)**	mg kg^{-1}	3.64
Potassium **(extractable)**		156

3.6.2 Bulk Density

The core soil sampler was employed to measure bulk density by adopting procedure adopted by Black and Hartge (1986):

$$\text{Bulk density} = \frac{\text{Weight of oven-dried soil}}{\text{Volume of core}}$$

3.6.3 Water Use Efficiency (kg/ha/mm)

The efficiency of water use based on seed yield of crops and water used by each crop was calculated using formula adopted by Gregory (1991):

WUE = Seed yield/water used

Here "water used" was the difference in soil water content (0-30 cm depth) measured at planting and harvest time, plus growing season rainfall in each case.

The moisture contents determined above were multiplied with bulk density to have water content in volumetric terms.

3.7ECONOMIC ANALYSIS

To compare the economic output of various soil additives and cropping systems economic analysis was done. The partial budgets were constructed for different cropping systems. Thus benefit/cost ratio of each cropping sequence was also calculated by including cost of production and gross benefits and net benefits. Marginal Rate of Return for different cropping sequence was determined by the formula as described by CIMMYT (1988).

$$\text{MRR} = \frac{\text{NB}}{\text{TVC}} \times 100$$

Where

MRR = Marginal Rate of Return (in percentage)

NB = Change in Net Benefits

TVC = Change in Total Variable Cost

3.7.1 Partial Budget Analysis

Partial budget include average yield, adjusted yield, gross field benefit and net benefits

Gross field benefits were calculated as (GB_f).

$$GB_f = P_f \times Y_{adj} \text{ (CIMMYT, 1998)}$$

Where,

GB_f = gross field benefits

P_f = field price

Y_{adj} = adjusted yield

Net benefits were calculated as

$$NB = GB_f - TCV \text{ (CIMMYT, 1998)}$$

Where,

NB = net benefits

TCV = total cost that vary

3.7.2 Dominance Analysis

Dominance analysis was carried out by listing the treatments with higher cost that vary (CIMMYT, 1988).

3.7.3 Marginal rate of return (MRR)

Farmer can change one practice to another by MRR which tells that what he gained from investment, it was calculated by using formula (CIMMYT, 1998)

$$MRR = \frac{\delta\ NB}{\delta\ TCV} \times 100$$

Where,

δ NB = change in net benefit

δ TCV = change in total cost that vary

3.8STATISTICAL ANALYSIS

For statistical analysis, data collected on various aspects were subjected to Fisher's Analysis of Variance Technique (ANOVA) using statistical package "Statistix 8.1"(www.statistix.com, e-mail: sales@statistix.com). The Least Significant Difference (LSD) test was used for comparison of treatment means.

Chapter 4

RESULT AND DISCUSSION

4.1SCREENING OF SOIL ADDITIVES FOR SOIL MOISTURECONSERVATION

4.1.1Soil Moisture Retentive Properties

The soil moisture characteristics curves prepared from soil moisture contents at different pressures ranging from 0.33-15 bars are presented in fig 4.1.1 (a→p) for control, qemisoyl, compost, FYM and gypsum and all possible combinations of the soil additives, respectively. The data regarding soil moisture at saturation, field capacity, permanent wilting point and plant available water were derived from soil moisture characteristic curves.

The soil moisture at saturation influenced by the application of different soil additives is given in Table 4.1.1. Qemisoyl @ 15 kg ha^{-1} and its combination with FYM @ 25 Mg ha^{-1}, compost @0.75 Mg ha^{-1} and gypsum @ 2.5 Mg ha^{-1}gave saturated watercontent of 0.44 m^{3} m^{-3}each that was higher than other treatments. Least saturated water content of 0.41 m^{3} m^{-3} was observed in soil with no additive. The overall saturated water content measured in soil samples treated with additives was higher than samples with no additive. Hayat and Ali (2004) reported that moisture content in the polymer treated soil increased from 30 to 85%. Saturation percentage increased significantly and the response was 17% better than the control. Hayat and Chaudhry (2001) reported a 30-80 per cent increase in saturation percentage with the application of polymer (aquasorb) over control, while Akhter et al. (2004) also reported that hydrogel boosted water holding capacity of the soil.Narjary et al., (2012) in their findings concluded that hydrogels can absorb water and release at the time of need, since water available to plants due to gel was four times higher than control treatments. Similarly, hydrogel treated soil maintains soil water contents for longer period of time as compared to control. Narjary et al., (2012) further depicted that hydrogel treated soil take 22 days to reach to critical soil water contents i.e. wilting point. Hydrogels also have potential to maintain higher water contents compared to control as Narjary et al., (2012) showed that hydrogels make 1.5-2 times higher water contents available to crop compared to control. Monnig, (2005) was of the view that hydrogels have potential to absorbs water four hundred times greater than the weight they have. Meanwhile, Nazarli et al, (2010) were of the view that hydrogels reduces the irrigation number to 50% by retaining maximum water in the soil. The increased availability of water in the soil similar to our findings was also reported by Wu et al, (2008) who stated that hydrogels could retained 10% more water in the soil compared to control treatments. Hayat and Ali (2004) recorded that moisture content in the polymer treated soil increased from 30 to 850%. Saturation percentage increased significantly and the response was 17% better than the control. Hayat and Chaudhry (2001) reported a 30-80 per cent increase in saturation percentage with the application of polymer (aquasorb) over control, while Akhter et al. (2004) also reported that hydrogel boosted water holding capacity of the soil.

Huang and Petrovic, (1994) in their work reported that soil additives could conserve water efficiently and improve the saturated water contents of the soil. Similarly, water retention capacity of soil could also be increased by hydrogel

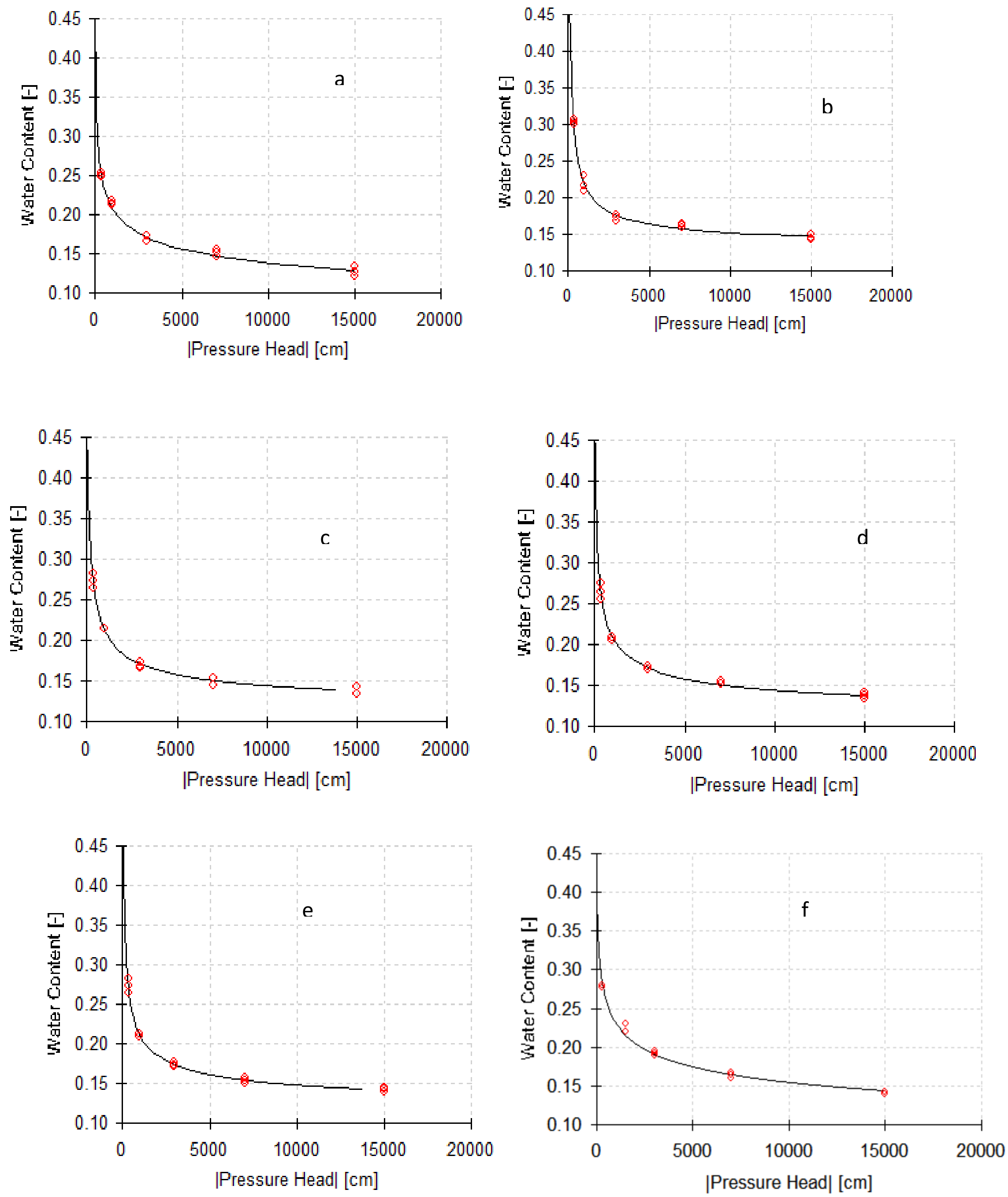


Figure-4.1.1 (a,b,c,d, e and f) water retentive curve (WRC) of soil simulated according to single porosity model using RETC-fit, for a) Soil (no additive), b) Qemisoyl @ 15 kg ha^{-1}, c) FYM @ 25 Mgha^{-1} , d) Compost @ 0.75 Mgha^{-1}, e) Gypsum @ 2.5 Mgha^{-1}, f) Qemisoyl @ 15 kg ha-1 + FYM @ 25 Mg ha-1)

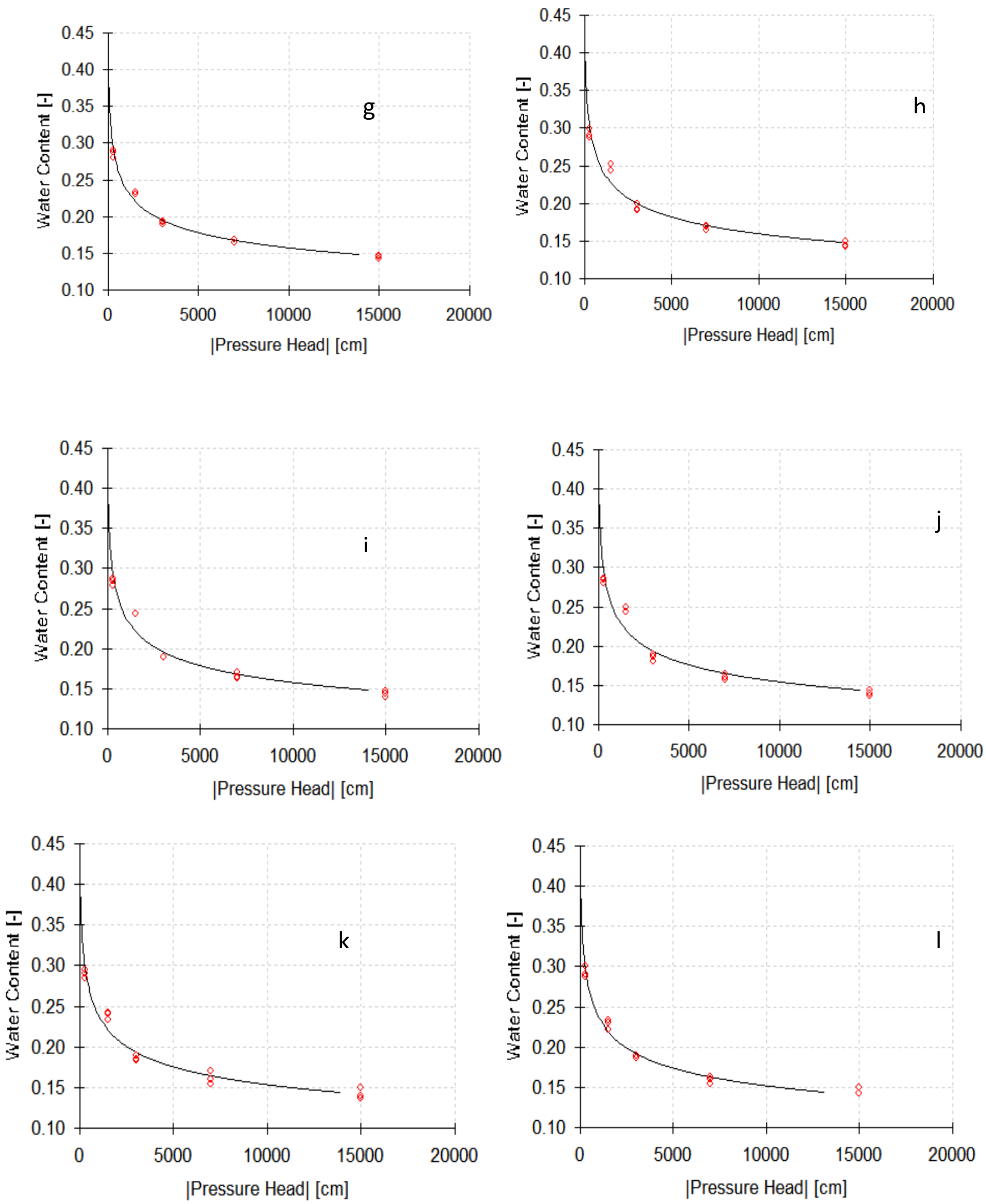


Figure 4.1.1 (g,h,I,j,k and l) g) WRC for Qemisoyl @ 15 kg ha^{-1} + Compost @ 0.75 Mg ha^{-1}, h) Qemisoyl @ 15 kg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}, i) FYM @ 25 Mg ha^{-1} + Compost @ 0.75 Mg ha^{-1}, J) FYM @ 25 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}, K) Compost @ 0.75 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}) Qemisoyl @ 15 kg ha^{-1} + FYM @ 25 Mg ha^{-1} + Compost @ 0.75 Mg ha^{-1})

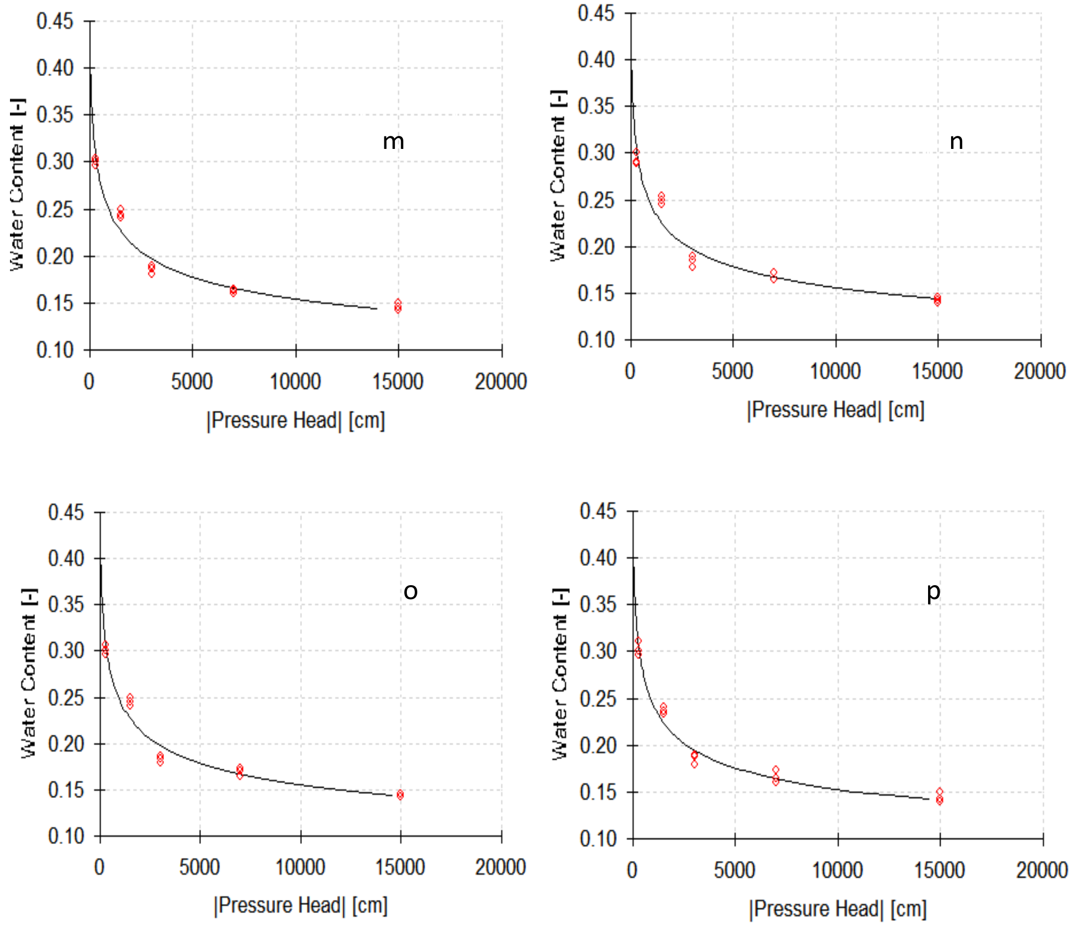


Figure 4.1.1 (m,n, o, p) WRC for m) Qemisoyl @ 15 kg ha^{-1} + FYM @ 25 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1},n)Qemisoyl @ 15 kg ha^{-1} + Compost @ 0.75 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}o) FYM @ 25 Mg ha^{-1} + Compost @ 0.75 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}p) Qemisoyl @ 15 kg ha^{-1} + FYM @ 25 Mg ha^{-1} + Compost @ 0.75 Mg ha^{-1} + Gypsum @ 2.5 Mgha^{-1}

application (Abedi-Koupai and Sohrab, 2004). Hydrogels have enormous capacity to absorb soil water as concluded by Wang and Gregg (1990). Kos and Le tan, (2003) in their findings concluded that hydrogels increases the field capacity of soil. Hüttermann et al., (1999) in their findings concluded that superabsorbent hydrogels increases water retention of the soil. The water retention increases exponentially with addition of hydrogels.

Huang and Petrovic, (1994) in their work reported that soil additives could conserve water efficiently and improve the saturated water contents of the soil. Similarly, water retention capacity of soil could also be increased by hydrogel application (Abedi-Koupai and Sohrab, 2004). Hydrogels have enormous capacity to absorb soil water as concluded by Wang and Gregg (1990). Kos and Le tan, (2003) in their findings concluded that hydrogels increases the field capacity of soil. Hüttermann et al., (1999) in their findings concluded that superabsorbent hydrogels increases water retention of the soil. The water retention increases exponentially with addition of hydrogels.

The data regarding soil moisture contents at field capacity influenced by the application of different soil additives is given in Table 4.1.2. The highest water contents at field capacity (0.28 m^3m^{-3}) were recorded for Qemisoyl @ 15 kg ha^{-1} and compost @ 0.75 Mg ha^{-1} and it was at par with different combinations of soil additives. Least water content of 0.25 m^3 m^{-3} at field capacity was observed in soil with no additive. Overall water contents at field capacity measured in soil samples treated with additives were higher over control. The results are in line with the work of several scientists (Hayat and Chaudhry, 2001; Akhter et al., 2004; Hayat and Ali, 2004). Qemisoyl as a hydrogels have enormous capacity to absorb soil water as concluded by Wang and Gregg (1990). Similar to our findings increased field capacity was reported by Kos and Letan, (2003) in their findings due to the application of hydrogels. Similarly, Koupai et al., (2008) in their results elaborated that hydrogels increase the soil water contents and can result in the significant reduction in the water demand of crops by alternatives sources like irrigation. Narjary and Aggarwal (2014) concluded in their work that addition of FYM with gel resulted to significantly increase in field capacity moisture content, plant-available water content and relative field capacity, retention pores (Ret P), water-stable structural units, and structural coefficient and reduced transmission pores (TP), penetration resistance, and saturated hydraulic conductivity (Ks).

The data regarding soil moisture contents at permanent wilting point influenced by the application of different soil additives is given in Table 4.4.3. Highest water contents at permanent wilting point ($0.15 m^3 m^{-3}$) were recorded for Qemisoyl @ 15 kg ha-1 and least water content of $0.13\ m^3\ m^{-3}$ at permanent wilting point was observed in soil with no additive. While water contents at permanent wilting point were at par with each other for other soil additives (Compost, FYM and Gypsum) and all possible combinations. Overall water contents at permanent wilting point measured in soil samples treated with additives were higher than samples with no additive. Our results were at par with the findings of Narjary et al., (2012) who concluded that hydrogel treated soil take 22 days to reach to critical soil water contents i.e wilting point.

The data regarding plant available soil moisture contents is given in Table 4.1.4. Highest plant available water contents ($0.14 m^3 m^{-3}$) were recorded for

Qemisoyl@ 15 kg ha-1and compost @ 0.75 Mg ha-1 and it was at par with different combinations of soil additives. While plant available water contents (0.13m^{3}m^{-3}) were at par with each other for other soil additives (FYM and Gypsum) and some other combinations. Least water content of 0.13 m^3 m^{-3} at permanent wilting point was observed in soil with no additive. Over all plant available water contents measured in soil samples treated with additives were higher than samples with no additive. The finding is in agreement with the work of El-Hady and Abo-Sedera (2006) who found that addition of soil amendments (hydrogel) resulted in increased water-holding capacity and increased availability of water to plants. Akhter et al. (2004) also reported that the addition of hydrogel increased the moisture retention (θr) at field capacity linearly (r =0.988) and thus the amount of plant available water significantly in both sandy loam and loam soils compared to the untreated soils. The hydrogel was effective in improving soil moisture availability and thus increased plant establishment.Highest plant available water contents due to application of Qemisoyl might be due to its hydrophilic nature as concluded by Abedi-Koupai, (2008) who reported that being hydrophilic in nature hydrogels might absorb water to maximum potential and releases that water at the time of need. Gilbert et al., (2014) concluded that hydrogels improves plant available water contents.

The data showed that the highest water content at saturation (0.45m^{3}m-3) was retained by qemisoyl @ 15 kg ha^{-1} and least water content of 0.39 m^3 m^{-3} was observed in soil with no additive. While water content was at par with each other for other soil additives (Compost, FYM and Gypsum) and their possible combinations. Overall water content measured in soil samples treated with additives was higher

Table 4.1.1 Moisture Content in different soil additives at Saturation m^3m^{-3}

Sr.No.1	**Treatments**	**Moisture Content at Saturation m^3m^{-3}**
1	Soil (no additive)	0.410±0.023
2	Qemisoyl @ 15 kg ha^{-1}	0.440±0.013
3	FYM @ 25 $Mgha^{-1}$	0.435±0.023
4	Compost @ 0.75 $Mgha^{-1}$	0.424±0.001
5	Gypsum @ 2.5 $Mgha^{-1}$	0.430±0.014
6	Qemisoyl @ 15 kg ha^{-1} + FYM @ 25 Mg ha^{-1}	0.434±0.015
7	Qemisoyl @ 15 kg ha^{-1} + Compost @ 0.75 Mg ha^{-1}	0.435±0.031
8	Qemisoyl @ 15 kg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.440±0.023
9	FYM @ 25 Mg ha^{-1} + Compost @ 0.75 Mg ha^{-1}	0.443±0.032
10	FYM @ 25 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.442±0.027
11	Compost @ 0.75 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.433±0.019
12	Qemisoyl @ 15 kg ha^{-1} + FYM @ 25 Mg ha^{-1} + Compost @ 0.75 Mg ha^{-1}	0.434±0.018
13	Qemisoyl @ 15 kg ha^{-1} + FYM @ 25 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.442±0.015
14	Qemisoyl @ 15 kg ha^{-1} + Compost @ 0.75 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.441±0.001
15	FYM @ 25 Mg ha^{-1} + Compost @ 0.75 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.439±0.003
16	Qemisoyl @ 15 kg ha^{-1} + FYM @ 25 Mg ha^{-1} + Compost @ 0.75 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.443±0.051

Table 4.1.2 Moisture contents in different soil additives at field capacity

Sr.No.	Treatments	Moisture Content at Field Capacity m^3m^{-3}
1	Soil (no additive)	0.251±0.012
2	Qemisoyl @ 15 kg ha^{-1}	0.284±0.002
3	FYM @ 25 $Mgha^{-1}$	0.272±0.003
4	Compost @ 0.75 $Mgha^{-1}$	0.276±0.015
5	Gypsum @ 2.5 $Mgha^{-1}$	0.274±0.021
6	Qemisoyl @ 15 kg ha^{-1} + FYM @ 25 Mg ha^{-1}	0.276±0.021
7	Qemisoyl @ 15 kg ha^{-1} + Compost @ 0.75 Mg ha^{-1}	0.275±0.015
8	Qemisoyl @ 15 kg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.279±0.006
9	FYM @ 25 Mg ha^{-1} + Compost @ 0.75 Mg ha^{-1}	0.273±0.009
10	FYM @ 25 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.276±0.016
11	Compost @ 0.75 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.272±0.021
12	Qemisoyl @ 15 kg ha^{-1} + FYM @ 25 Mg ha^{-1} + Compost @ 0.75 Mg ha^{-1}	0.274±0.030
13	Qemisoyl @ 15 kg ha^{-1} + FYM @ 25 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.276±0.001
14	Qemisoyl @ 15 kg ha^{-1} + Compost @ 0.75 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.275±0.006
15	FYM @ 25 Mg ha^{-1} + Compost @ 0.75 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.274±0.006
16	Qemisoyl @ 15 kg ha^{-1} + FYM @ 25 Mg ha^{-1} + Compost @ 0.75 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.277±0.021

Table 4.1.3 Moisture Content in different soil additives at Permanent Wilting Point (m^3m^{-3})

Sr.No.	Treatments	Moisture Content at Permanent Wilting Point (m^3m^{-3})
1	Soil (no additive)	0.128±0.013
2	Qemisoyl @ 15 kg ha^{-1}	0.146±0.002
3	FYM @ 25 $Mgha^{-1}$	0.140±0.011
4	Compost @ 0.75 $Mgha^{-1}$	0.140±0.009
5	Gypsum @ 2.5 $Mgha^{-1}$	0.143±0.012
6	Qemisoyl @ 15 kg ha^{-1} + FYM @ 25 Mg ha^{-1}	0.142±0.003
7	Qemisoyl @ 15 kg ha^{-1} + Compost @ 0.75 Mg ha^{-1}	0.144±0.014
8	Qemisoyl @ 15 kg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.142±0.006
9	FYM @ 25 Mg ha^{-1} + Compost @ 0.75 Mg ha^{-1}	0.141±0.011
10	FYM @ 25 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.143±0.000
11	Compost @ 0.75 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.144±0.014
12	Qemisoyl @ 15 kg ha^{-1} + FYM @ 25 Mg ha^{-1} + Compost @ 0.75 Mg ha^{-1}	0.139±0.002
13	Qemisoyl @ 15 kg ha^{-1} + FYM @ 25 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.14±0.003
14	Qemisoyl @ 15 kg ha^{-1} + Compost @ 0.75 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.141±0.004
15	FYM @ 25 Mg ha^{-1} + Compost @ 0.75 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.142±0.013
16	Qemisoyl @ 15 kg ha^{-1} + FYM @ 25 Mg ha^{-1} + Compost @ 0.75 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.143±0.014

Table 4.1.4 Plant available water content in different soil additives (m^3m^{-3})

Sr.No.1	Treatments	Plant available water contents (m^3m^{-3})
1	Soil (no additive)	0.123±0.012
2	Qemisoyl @ 15 kg ha^{-1}	0.138±0.002
3	FYM @ 25 $Mgha^{-1}$	0.132±0.010
4	Compost @ 0.75 $Mgha^{-1}$	0.136±0.012
5	Gypsum @ 2.5 $Mgha^{-1}$	0.131±0.012
6	Qemisoyl @ 15 kg ha^{-1} + FYM @ 25 Mg ha^{-1}	0.134±0.006
7	Qemisoyl @ 15 kg ha^{-1} + Compost @ 0.75 Mg ha^{-1}	0.131±0.007
8	Qemisoyl @ 15 kg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.137±0.009
9	FYM @ 25 Mg ha^{-1} + Compost @ 0.75 Mg ha^{-1}	0.132±0.011
10	FYM @ 25 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.133±0.021
11	Compost @ 0.75 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.128±0.003
12	Qemisoyl @ 15 kg ha^{-1} + FYM @ 25 Mg ha^{-1} + Compost @ 0.75 Mg ha^{-1}	0.135±0.003
13	Qemisoyl @ 15 kg ha^{-1} + FYM @ 25 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.136±0.007
14	Qemisoyl @ 15 kg ha^{-1} + Compost @ 0.75 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.134±0.031
15	FYM @ 25 Mg ha^{-1} + Compost @ 0.75 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.132±0.004
16	Qemisoyl @ 15 kg ha^{-1} + FYM @ 25 Mg ha^{-1} + Compost @ 0.75 Mg ha^{-1} + Gypsum @ 2.5 Mg ha^{-1}	0.134±0.003

than samples with no additive. So only sole soil additives were used for further field study rather than using their combinations as no combinations retained higher water contents than qemisoyl sole.

On the basis of laboratory study the soil moisture contents were higher for individual soil additives rather than their combinations. So, second experiment was conducted in field conditions to check the performance of soil additives on different cropping systems.

4.2 FIELD TRIALS

4.2.1 Soil Moisture Content

4.2.1.1 Soil moisture content at summer sowing

The data regarding soil moisture content at summer plantation presented in Appendix 3 showed that soil additives depicted their difference for water retention in the upper soil profile (0-30 cm). Among soil additives, the highest soil water content was recorded under hydrogel treatment and the lowest water content was recorded in control plots (8.95 %) followed by gypsum plots (9.26 %) whereas, FYM (10.01 %) and compost (10.18 %) were at par with each other (Table 4.2.1). Similarly, soil water contents varied potentially under all the cropping systems, the highest soil water content was recorded under CS2 (10.43 %) and lowest was recorded under CS3 (9.23 %), while soil moisture contents for CS1 (10.16 %) and CS4 (10.07 %) were at par with each other. Soil water contents in the soil profile remained higher during 2010 than 2011. Summer pre-sowing water contents during 2010 in the upper soil profile (0-30 cm) were 10.70 % while during 2011 they were reduced to 9.24%. The interactive effect among Y x CS was significant while other interactions were non-significant. Three way interactive effect i.e. Y x CS x SA is presented in table 4.2.2.

An increase in soil water contents at the depth of 30-60 cm than 0-30 cm was recorded (Appendix 4). Use of soil additives improved soil water holding capacity and among the soil additives, highest soil water content was recorded for hydrogel (11.93%), while FYM (10.38 %) and compost (10.57%) were at par with each other (4.2.1). The lowest soil moisture content was recorded in control plots (9.13 %) and it was lesser than gypsum (9.78 %). The cropping systems also varied significantly for soil moisture content. The highest soil water content was recorded for CS1 (11.20%) and lowest was recorded for CS4 (9.88%) followed by CS3 (9.91 %) at the depth of 30-60 cm.Among the years, higher soil water content (11.54 %) at the depth of 30-60 cm was observed during the 2010 and lower moisture content (9.25%) was recorded during 2011. The interactive effect among Y x CS was significant while other interactions were non-significant. Three way interactive effect i.e. Y x CS x SA is presented in Table 4.2.3.

Summer pre sowing moisture content at the depth of 60-90 cm was higher than upper layers (Appendix 5). Among additives, the highest soil moisture content was recorded for hydrogel (16.06 %), while compost (14.24%) FYM (14.00 %) and control (13.95 %) were at par with each other. The lowest soil moisture content was recorded in the plots where gypsum was applied (12.95%). All the cropping systems also varied significantly for soil moisture contents. The higher soil water content was recorded for CS2 (14.84 %) followed by CS1 (14.64%) and lowest were recorded for

Table 4.2.1 Summer pre sowing soil moisture content (%) at 0-90 cm depth as influenced by different soil additives and cropping systems

Year	0-30	30-60	60-90
2010	10.71A	11.54A	15.37A
2011	9.25B	9.25B	13.12B
LSD	0.048	0.20	0.24
Cropping System			
CS1	10.16B	11.20A	14.65A
CS2	10.43A	10.59B	14.84A
CS3	9.23C	9.91C	13.27C
CS4	10.1B	9.887C	14.22B
LSD	0.23	0.11	0.37
Soil Additives			
Control	8.95C	9.31D	13.95B
Hydrogel	11.48A	11.93A	16.07A
FYM	10.01B	10.38B	14.00B
Compost	10.18B	10.58B	14.25B
Gypsum	9.26C	9.78C	12.96C
LSD	0.33	0.26	0.46

In all the data tables, any two mean not sharing a common letter differs significantly at 5% level of significance

CS= Cropping System, Y= Year, SA= Soil Additives
CS1: Summer Fallow-wheat
CS2: Mungbean-wheat
CS3: Sorghum- wheat
CS4: Sorghum + mungbean- wheat

Table 4.2.2 Interactive effects of Summer pre sowing soil moisture content (%) at 0-30 cm depth as influenced by different soil additives and cropping systems during both years

Soil Additives	2010				2011				Mean
	CS1	CS2	CS3	CS4	CS1	CS2	CS3	CS4	
Control	8.367NS	11.733	8.267	10.067	9.767	6.867	8.367	8.167	8.95C
Hydrogel	10.733	15.033	10.633	12.867	12.533	8.833	10.733	10.433	11.475A
FYM	9.367	13.1	9.267	11.233	10.933	7.733	9.367	9.1	10.013B
Compost	9.533	13.333	9.433	11.4	11.1	7.867	9.533	9.233	10.179B
Gypsum	8.9	12.5	8.8	9.533	10.4	7.333	7.933	8.667	9.258C
Mean	9.38C	13.14A	9.28C	11.02B	10.95B	7.73D	9.19C	9.12C	

LSD for Y x CS 0.3811

LSD for Y x CS x SA NS

Table 4.2.3 Interactive effects of Summer pre sowing soil moisture content (%) at 30-60 cm depth as influenced by different soil additives and cropping systems during both years

Soil Additives	2010				2011				Mean
	CS1	CS2	CS3	CS4	CS1	CS2	CS3	CS4	
Control	10.433NS	11.133	9.467	10.133	9.267	7.9	8.433	7.733	9.313D
Hydrogel	13.967	14.2	12.033	12.833	11.8	10.033	10.733	9.867	11.933A
FYM	12.133	12.333	10.467	11.233	10.267	8.733	9.333	8.567	10.383B
Compost	12.367	12.567	10.667	11.4	10.467	8.9	9.5	8.733	10.575B
Gypsum	11.567	11.733	9.967	10.2	9.767	8.333	8.5	8.167	9.779C
Mean	12.093A	12.393A	10.52C	11.16B	10.31C	8.78E	9.30D	8.61E	

LSD for Y x CS 0.3085

LSD for Y x CS x SA NS

Table 4.2.4Interactive effects of Summer pre sowing soil moisture content (%) at 60-90 cm depth as influenced by different soil additives and cropping systems during both years

Soil Additives	2010				2011				Mean
	CS1	CS2	CS3	CS4	CS1	CS2	CS3	CS4	
Control	15.667def	16.667cd	14.2g-k	15.167e-h	13.933h-l	11.833o-s	12.6m-p	11.567p-s	13.954B
Hydrogel	15.033e-h	21.067a	14.867e-h	18b	17.533bc	12.4m-p	15.033e-h	14.6f-i	16.067A
FYM	13.10k-n	18.3b	12.967k-o	15.7def	15.3efg	10.8st	13.1k-n	12.733l-p	14.00B
Compost	13.333j-n	18.633b	13.167k-n	16de	15.533def	11rst	13.333j-n	12.967k-o	14.246B
Gypsum	12.5m-p	17.433bc	12.30m-q	13.367i-m	14.533f-j	10.3t	11.133q-t	12.1n-r	12.958C
Mean	13.93C	18.42A	13.5CD	15.65B	15.367C	11.267F	13.04DE	12.793E	

LSD for Y x CS 0.5627

LSD for Y x CS x SA 1.2583

CS3 (13.27%) and it was higher than CS4 (14.22%) at the depth of 30-60 cm. Among years, higher soil water content(15.37 %) at the depth of 60-90 cm was observed during the 2010 and lower moisture contents (13.11 %) were recorded during 2011. The interactive effects among Y x CS and Y x CS x SA were significant while other interactions were non-significant. Three way interactive effect i.e. Y x CS x SA is presented in Table 4.2.4.

The soil moisture content at summer plantation remained highest under hydrogel treatments compared to control in our findings which might be due to strong absorptive capacity of hydrogels. Similar results were reported by Zhang et al., (2007) who emphasized on the use of hydrogel to conserve soil water with integration of modern techniques to improve crop yield in rainfed areas. The positive effect of hydrogels to improve water status under dry conditions was reported by Keshavars et al., (2012). Similarly hydrogel improves soil water holding capacity, minimizes evapotranspiration and allow plants to survive under water stress (Chirino et al., 2008). The benefit of hydrogels to improve soil water contents were also confirmed by Landis (2012) who concluded that hydrogel could be good source to mitigate dry seasons.

4.2.1.2 Summer post-harvest/ winter pre sowing soil moisture content

Soil water contents differed significantly under all the soil additives among all the cropping patterns during both the years (Appendix 6). Summer post-harvest (winter pre sowing) soil additives showed their difference for water retention in the upper soil profile (Table 4.2.5). The highest soil water contents (16.42 %) were recorded for hydrogel treatments and lowest water contents were recorded from

Table 4.2.5 Summer post-harvest (Winter pre-sowing) moisture content (%) at 0-90 cm depth as influenced by different soil additives and cropping systems during both years

Year	0-30	30-60	60-90
2010	12.475B	12.485B	16.913B
2011	16.048A	12.695A	17.7A
LSD	0.1396	0.1185	0.2223
Cropping System			
CS1	14.42B	13.613A	18.01A
CS2	15.057A	12.737B	17.74A
CS3	13.157C	12.07C	16.237C
CS4	14.413B	11.94C	17.24B
LSD	0.3308	0.1301	0.4296
Soil Additives			
Control	12.796C	11.271D	16.913B
Hydrogel	16.417A	14.446A	19.533A
FYM	14.304B	12.583B	17.012B
Compost	14.558B	12.808B	17.325B
Gypsum	13.233C	11.842C	15.75C
LSD	0.4494	0.3095	0.5546

Table 4.2.6 Summer post-harvest (Winter pre-sowing) soil moisture content (%) at 0-30 cmdepth as influenced by different soil additives and cropping systems during both years

Soil Additives	2010				2011				Mean
	CS1	CS2	CS3	CS4	CS1	CS2	CS3	CS4	
Control	13.167NS	9.30	11.30	11.00	12.60	17.57	12.40	15.03	12.796C
Hydrogel	16.90	11.97	14.50	14.10	16.10	22.53	15.90	19.33	16.417A
FYM	14.73	10.40	12.63	12.27	14.03	19.63	13.90	16.83	14.304B
Compost	15.00	10.60	12.87	12.47	14.30	19.97	14.13	17.13	14.558B
Gypsum	14.00	9.93	10.70	11.67	13.37	18.67	13.23	14.30	13.233C
Mean	14.76C	10.44F	12.40E	12.30E	14.08D	19.67A	13.91D	16.5B	

LSD for Y x CS 0.5403

LSD for Y x CS x SA NS

Table 4.2.7Summer post-harvest (Winter pre-sowing) soil moisture content (%) at 30-60 cmdepth as influenced by different soil additives and cropping systems during both years

Soil Additives	2010				2011				Mean
	CS1	CS2	CS3	CS4	CS1	CS2	CS3	CS4	
Control	11.467NS	12.267	10.4	11.1	12.5	10.633	11.367	10.433	11.271D
Hydrogel	15.333	15.6	13.233	14.167	15.9	13.533	14.5	13.3	14.446A
FYM	13.367	13.567	11.533	12.333	13.9	11.833	12.6	11.533	12.583B
Compost	13.6	13.8	11.767	12.567	14.133	12	12.833	11.767	12.808B
Gypsum	12.7	12.9	11	11.2	13.233	11.233	11.467	11	11.842C
Mean	13.293B	13.627AB	11.587D	12.273C	13.933A	11.847D	12.553C	11.607D	

LSD for Y x CS 0.3599

LSD for Y x CS SA NS

control plots (12.79%) followed by gypsum plots (13.23%) whereas, FYM (14.30 %) and compost (14.55%) were at par with each other. Similarly, soil water contents varied potentially under all the cropping systems. The highest soil water contents were recorded under CS2 (15.06%) and lowest were recorded under CS3 (13.15 %) at the depth of 0-30 cm while soil moisture contents for CS1 (14.41%) and CS4 (14.42%) were at par with each other. In the same way water contents during 2011 in the upper soil profile (0-30 cm) were 16.05 % while during 2012 they were reduced to 12.47 %. The interactive effect among Y x CS was significant while other interaction were non-significant. Three way interactive effect i.e. Y x CS x SA has been presented in table 4.2.6.

Similarly, higher soil water contents at the depth of 30-60 cm compared to 0-30 cm was recorded (Appendix 7). Use of soil additives enhanced soil water retention and among the soil additives, highest soil water contents was recorded for hydrogel (14.44%), while FYM (12.58 %) and compost (12.80 %) were at par with each other (Table 4.2.5). The lowest soil moisture contents was recorded in control plots (11.27%) and it was less than gypsum (11.84%). All the cropping systems were varied significantly for soil moisture contents. The highest soil water contents were recorded for CS1 (13.61%) and lowest were recorded for CS4 (11.97%) followed by CS3 (12.07%) at the depth of 30-60 cm. Soil moisture contents varied significantly for both the years at the depth of 30-60. The higher soil water contents (12.69%) at the depth of 30-60 cm were observed during the 2011 and lower moisture contents (12.48 %) were recorded during 2010. The interactive effect among Y x CS was significant while other

Table 4.2.8 Summer post-harvest (Winter pre-sowing) soil moisture content (%) at 60-90 cm depth as influenced by different soil additives and cropping systems during both years

Soil Additives	2010				2011				Mean
	CS1	CS2	CS3	CS4	CS1	CS2	CS3	CS4	
Control	17.2h-k	18.367e-h	15.633l-o	16.667i-l	18.767d-g	15.967k-n	17.067h-l	15.633l-o	16.913B
Hydrogel	16.5jkl	23.133a	16.4j-m	19.833b-e	23.667a	16.733i-l	20.3bc	19.7b-e	19.533A
FYM	14.433op	20.167bcd	14.233op	17.267h-k	20.6bc	14.567nop	17.667g-j	17.167h-k	17.012B
Compost	14.667nop	20.533bc	14.5nop	17.6g-j	20.967b	14.833nop	18f-i	17.5g-j	17.325B
Gypsum	13.7p	19.2c-f	13.567p	14.667nop	19.6b-e	13.9p	15m-p	16.367j-m	15.75C
Mean	15.30C	20.28A	14.867C	17.207B	20.72A	15.2C	17.607B	17.273B	

LSD for Y x CS 0.6705
LSD for Y x CS x SA 1.4992

interactions were non-significant. Three way interactive effect i.e. Y x CS x SA has been presented in table 4.2.7.

Similarly, summer post-harvest (winter pre sowing) moisture contents at the depth of 60-90 cm were higher than upper all layers (Appendix 8). The highest soil moisture contents was recorded for hydrogel (19.53%), while compost (17.32%) FYM (17.01%) and control (16.91%) were at par with each other. The lowest soil moisture contents were recorded in the plots where gypsum was applied (15.75%). All the cropping systems were differed significantly for soil moisture contents. Highest soil water contents were recorded for CS1 (18.01%) followed by CS2 (17.94%) and lowest were recorded for CS3 (16.23%) and it was higher than CS4 (17.24%) at the depth of 60-90 cm. Higher soil water contents(17.70%) at the depth of 60-90 cm were observed during the 2011 and lower moisture contents (16.91 %) were recorded during 2010. The interactive effect among Y x CS was significant while other interaction were non-significant. Three way interactive effect i.e. Y x CS x SA has been presented in table 4.2.8.

Monnig, (2005) in their findings concluded that hydrogels can improve the soil water contents in the soil compared to control. Similar results were reported by Widiatuti,(2008) and Green, (2004) who concluded that hydrogels have potential to increase soil water contents under arid conditions of world. The increased availability of water in the soil similar to our findings was also reported by Wu et al, (2008) who stated that hydrogels could retained 10% more water in the soil compared to control treatments.

4.2.1.3 Soil moister contents at winter harvesting

Winter post-harvest soil water contents at the depth of 0-30 cm were recorded. All the soil additives under all the cropping systems during both years differed potentially for moisture contents (Appendix 9). Use of soil additives enhanced soil water retention and among the soil additives, the highest soil water contents was recorded for hydrogel (17.61%), while FYM (15.98%) and compost (16.17%) were at par with each other (Table 4.2.9). The lowest soil moisture contents was recorded in control plots (14.9%) and it was less than gypsum (15.45%). All the cropping systems were differed potentially for soil moisture contents. The highest soil water contents were recorded for CS2 (17.29%) and lowest were recorded for CS1 (15.23%). Soil moisture contents differed significantly for both the years at the depth of 0-30 cm. Maximum soil water contents (17.03%) at the depth of 0-30 cm were observed during the 2011 and minimum soil moisture contents (15.01%) were recorded during 2010. The interactive effect among Y x CS was significant while other interaction were non-significant. Three way interactive effect i.e. Y x CS x SA has been presented in table 4.2.10.

Whereas, winter post-harvest moisture contents at the depth of 30-60 cm were higher than upper layer. All the soil additives under all the cropping systems during both years differed potentially for moisture contents (Appendix 10). The highest soil moisture contents were recorded for hydrogel (18.92%), while FYM (17.08%) and compost (17.31%) were at par with each other. The lowest soil moisture contents were recorded in the control plots (15.89%).

All the cropping systems were differed considerably for soil moisture contents. Highest soil water contents were recorded for CS2 (18.53%) and lowest were recorded for CS1 (16.25%) and it was higher than CS3 (16.48%) at the depth of 30-60 cm. The higher soil water contents (18.24%) at the depth of 30-60 cm were observed during the 2011 and lower moisture contents (16.01 %) were recorded during 2010. The interactive effect among Y x CS was significant while other interaction were non-significant. Three way interactive effect i.e. Y x CS x SA has been presented in table 4.2.11.

Similarly, soil water contents differed significantly under all the soil additives among all the cropping patterns during both the years at the depth of 60-90 cm (Appendix 11). Rabi post-harvest water contents during 2010-11 were 16.91% while during 2011-12 they were increased to 17.7%. Soil additives showed their difference for water retention in the deeper soil profile.

Highest soil water contents (19.53%) were recorded for hydrogel treatments and lowest water contents were recorded from the plots where gypsum was added (15.75%) whereas, compost (17.32%) FYM (17.01%) and control treatments (16.91 %) were at par with each other. Similarly, soil water contents differed potentially under all the cropping systems. Highest soil water contents were recorded under CS1 (18.01%) fallowed by CS2 (17.74 %) and lowest were recorded under CS3 (16.23%) at the depth of 60-90 cm and it was less than CS4 (17.24%). All the interactive effects were non-significant. Three way interactive effect i.e. Y x CS x SA has been presented in table 4.2.12.

Table 4.2.9 Winter post-harvest soil moisture content (%) at 0-90 cm depth as influenced by different soil additives and cropping systems during both years

Years	0-30	30-60	60-90
2010-11	15.015B	16.015B	14.885B
2011-12	17.038A	18.245A	16.882A
LSD	0.1127	0.1297	0.6813
Cropping Systems			
CS1	15.230D	16.253D	15.093D
CS2	17.293A	18.533A	17.13A
CS3	15.437C	16.483C	15.303C
CS4	16.147B	17.25B	16.007B
LSD	0.031	0.048	0.159
Soil Additives			
Control	14.904D	15.896D	14.446C
Hydrogel	17.613A	18.892A	17.025A
FYM	15.983B	17.088B	15.454B
Compost	16.179B	17.313B	15.617B
Gypsum	15.454C	16.462C	16.875A
LSD	0.2524	0.2817	0.4532

Table 4.2.10 Interactive effect of Y x CS x SA on winter post-harvest soil moisture content (%) at 0-30 cm depth as influenced by different soil additives and cropping systems during both years

Soil Additives	2010				2011				Mean
	CS1	CS2	CS3	CS4	CS1	CS2	CS3	CS4	
Control	13.333	15.033	13.533	14.067	15.033	17.067	15.233	15.933	14.904D
Hydrogel	15.633	17.767	15.833	16.6	17.767	20.367	18.033	18.9	17.613A
FYM	14.267	16.133	14.433	15.067	16.133	18.367	16.333	17.133	15.983B
Compost	14.433	16.3	14.6	15.267	16.3	18.6	16.567	17.367	16.179B
Gypsum	13.8	15.6	14	14.6	15.6	17.7	15.8	16.533	15.454C
Mean	14.293E	16.167C	14.48E	15.12D	16.167C	18.42A	16.393C	17.173B	

LSD for Y x CS 0.2891

LSD for Y x CS x SA NS

Table 4.2.11 Interactive effect of (Y x CS x SA) on winter post-harvest soil moisture content (%) at 30-60 cm depth as influenced by different soil additives and cropping systems during both years

Soil Additives	2010				2011				Mean
	CS1	CS2	CS3	CS4	CS1	CS2	CS3	CS4	
Control	14.167NS	16.033	14.367	15.033	16.033	18.233	16.267	17.033	15.896D
Hydrogel	16.7	19.1	16.933	17.733	19.1	21.9	19.333	20.333	18.892A
FYM	15.167	17.233	15.367	16.133	17.233	19.733	17.5	18.333	17.088B
Compost	15.367	17.467	15.567	16.3	17.467	20	17.733	18.6	17.313B
Gypsum	14.667	16.633	14.867	15.467	16.633	19	16.9	17.533	16.462C
Mean	15.213E	17.293C	15.42E	16.133D	17.293C	19.773A	17.547C	18.367B	

LSD for Y x CS 0.3231

LSD for Y x CS x SA NS

The positive effect of hydrogels to improve soil water status under dry conditions was reported by Keshavars et al., (2012). They concluded that application of super absorbent polymer resulted to increased WUE similar to our findings. According to Guilherme et al., (2005) and Li et al., (2005) hydrogels have potential to absorbs 500 times higher water than their own weight. Meanwhile Zhang et al., (2007) emphasized on the use of hydrogel to conserve soil water with integration of modern techniques to improve soil water status in rainfed areas. The benefit of hydrogels to improve soil water contents were also confirmed by Landis (2012) who concluded that hydrogel could be good source to mitigate dry seasons. Gilbert et al., (2014) concluded that hydrogels have potential to increase soil water from eight to ten percent. Hydrogel, hydrophilic nature has been proved earlier by Abedi-Koupai, (2008) and he concluded that hydrogel could be good source to conserve soil water. Similarly hydrogel improves soil water holding capacity, minimizes evapotranspiration and allow plants to survive under water stress (Chirino et al., 2008).

4.2.2 Soil Bulk Density (g/cm^3)

The data regarding soil bulk density at summer plantation presented in ANOVA Table 12 showed that soil additives depicted their difference for soil bulk density in the upper soil profile (0-30 cm). Among soil additives, the highest bulk density (1.45 g/cm^3) was recorded under hydrogel treatment and it was higher (1.36 g/cm^3) than compost while the lowest bulk density was recorded in control plots (1.27 g/cm^3) whereas, FYM (1.34 g/cm^3) and gypsum (1.34 g/cm^3) were at par with each other (Table 4.2.13). Similarly, soil bulk density varied potentially under all the

Table 4.2.12 Interactive effect of (Y x CS x SA) on winter post-harvest soil moisture content (%) at60-90 cm depth as influenced by different soil additives and cropping systems during both years

Soil Additives	2010				2011				Mean
	CS1	CS2	CS3	CS4	CS1	CS2	CS3	CS4	
Control	12.967	14.567	13.133	13.667	14.567	16.5	14.767	15.4	14.446C
Hydrogel	15.133	17.167	15.333	16.067	17.167	19.633	17.433	18.267	17.025A
FYM	13.8	15.6	13.967	14.6	15.6	17.733	15.8	16.533	15.454B
Compost	13.933	15.767	14.1	14.733	15.767	17.9	16	16.733	15.617B
Gypsum	15	17	15.233	15.933	17	19.433	17.267	18.133	16.875A
Mean	14.167	16.02	14.353	15	16.02	18.24	16.253	17.013	

LSD for Y x CS NS

LSD for Y x CS x SA NS

Table 4.2.13 Interactive effect of (Y x CS x SA) on soil bulk density (g cm^{-3}) at the depth of 0-30 cm depth as influenced by different soil additives and cropping systems during both years

Soil Additives	2010-11				2011-12				Mean
	CS1	CS2	CS3	CS4	CS1	CS2	CS3	CS4	
Control	1.3233lk	1.4567g	1.2900m	1.3233kl	1.3867i	1.6233a	1.4033i	1.4767ef	1.41C
Gypsum	1.3233lk	1.3900i	1.3067lm	1.3367jk	1.43h	1.5500c	1.4600fg	1.4933de	1.45A
FYM	1.3233lk	1.3233kl	1.4300h	1.3533j	1.3867i	1.4767ef	1.5967b	1.5067d	1.43B
Compost	1.3233lk	1.3367kj	1.4567g	1.3367jk	1.3467j	1.4933de	1.6233a	1.4033i	1.42C
Hydrogel	1.4300h	1.3533j	1.3900i	1.3400jk	1.5967b	1.5067d	1.5500c	1.4600fg	1.41C
Mean	1.3447E	1.3720D	1.3747D	1.3380E	1.4293C	1.5300A	1.5267A	1.4680B	

LSD for Y x CS 0.008657

LSD for Y x CS x SA 0.0194

cropping systems. The highest bulk density was recorded under CS2 and CS3 (1.45 g/cm^3) and lowest was recorded under CS1 (1.39 g/cm^3), which was significantly lower than CS4 (1.40 g/cm^3). Soil bulk density in the soil upper profile remained higher during 2011 than 2010. Summer pre sowing bulk density during 2010 in the upper soil profile (0-30 cm) was 1.36 g/cm^3 while during 2011 it was increased to 1.49 g/cm^3.

Meanwhile all the interactive effects viz. Y x CS, Y x SA, CS x SA and Y x CS x SA were highly significant. Three way interactive effects are presented in table 4.2.13 which showed that the highest soil bulk density (1.62 g/cm^3) was recorded under CS2 and CS3 during 2011 from control as well as from the plots where FYM was applied. The findings of this study are supported by work of Hayat and Ali (2004) who reported a reduction in bulk density with the application of polymers. The reduction in bulk density was 4 to 80%. Hayat and Chaudhry (2001) also conducted studies on polymers and reported that bulk density was reduced from 2.63 to 2.50 due to the application of aquasorb.Hussien*et al*., (2012) in their findings concluded that hydrogel can improve the bulk density of soil. They reported that due to addition of hydrogel in soil the bulk density values changes in the range of 90.1%–71.43% compared to hydrogel free soil sample. Similarly, Sharma et al. (2014) was of the view that hydrogels application might improve the water retention in the soil by modifying its physical properties. Different polymers have been used widely to improve soil structure and properties like water holding capacity (Hayat and Ali, 2004 and Orts et al., 2000), porosity (Bhardwaj and Mclaughlin, 2007, Bhat et al., 2009) and minimize erosion.

4.2.3 Water Use Efficiency

4.2.3.1 Summer water use efficiency (kg/ha/mm)

The data regarding water use efficiency from summer plantation presented in ANOVA Table 13 showed that soil additives depicted their difference for water use efficiency. Among soil additives, the highest water use efficiency (1.39) was recorded for hydrogel treatment fallowed by compost (1.35) and FYM (1.34) while the lowest water use efficiency was recorded in control plots (1.28). Similarly, water use efficiency for summer plantation varied considerably under all the cropping systems. The highest water use efficiency was recorded for CS4 (2.71) and it was potentially higher than CS2 (1.47) while the lowest water use efficiency was recorded under CS1 (0), which was significantly lower than CS3 (1.14). Water use efficiency for both the summer seasons remained statistically non significant. Meanwhile all the interactive effects viz. Y x CS, Y x SA, CS x SA and Y x CS x SA were statistically non-significant. Three way interactive effects has been presented in table 4.2.14. Leciejewski (2009) and Paluszek and Zembrowski (2008) concluded that hydrogel could be good option to increase water use efficiency and crop productivity. Similarly, water retention capacity of soil could also be increased by hydrogel application (Abedi-Koupai and Sohrab, 2004). Improved soil structure due to the application of hydrogels was reported by Yangyuoru et al., (2006) who elaborated that with the application of soil additives water availability to the crops could be increased. Hüttermann et al. (1999) in their findings concluded that water retention in the soil was exponentially related with the addition of hydrogels resulted to the modification in the water potential of soil and water use efficiency. He reported that due to the application of hydrogels seedlings can survive easily under drought compared to control. The WUE under rainfed agriculture could be improved by soil managements which includes use of soil additives like hydrogels. The hydrogels increases soil water availability to the crop resulted to high WUE. Sharma, (2004) in his findings concluded that hydrogels have potential to conserve soil water and crop establishment. The good establishment of crop further resulted to good vegetative and reproductive growth of crop and highest yield. Similar results were also reported by Allahdadi et al., (2005) and El-Hady et al., (2009). The work of Huang and Petrovic, (1994) confirmed the use of super absorbent polymers to conserve soil water. Meanwhile, Zhang et al., (2007) concluded that hydrogels have great potential to increase plant growth and production indirectly by storing soil water and reclamation of soil. Our results were similar to Johnson and Leah, (1990) who concluded that hydrogel are good source to store water and have potential to improve rainfed agriculture.

4.2.3.2 Winter Water Use Efficiency (kg/ha/mm)

The data regarding wheat water use efficiency has been presented in ANOVA Table 14 showed that soil additives depicted their difference for water use efficiency. Among soil additives, the highest water use efficiency (13.54) was recorded for gypsum treatment fallowed by FYM (13.33) while the lowest water use efficiency (12.87) was recorded from the plots where compost was used (Table 4.5.1) whereas, water use efficiency for hydrogel (13.17) and control (13.13) treatments were at par with each other. Similarly, water use efficiency for wheat crop differed considerably under all the cropping systems. The highest water use efficiency was recorded for CS2

Table 4.2.14 Interactive effect of (Y x CS x SA) on summer water use efficiency (kg/ha/mm)as influenced by different soil additives and cropping systems during both years

Soil Additives	2010-11				2011-12				Mean
	CS1	CS2	CS3	CS4	CS1	CS2	CS3	CS4	
Control	0NS	1.4233	1.0467	2.75	0	1.4467	1.0433	2.56	1.2838C
Gypsum	0	1.4733	1.2333	2.9567	0	1.5367	1.2533	2.6933	1.3933A
FYM	0	1.4233	1.1033	2.8733	0	1.53	1.1633	2.6333	1.3408ABC
Compost	0	1.4633	1.1467	2.9	0	1.52	1.17	2.6533	1.3567AB
Hydrogel	0	1.4	1.13	2.8667	0	1.49	1.1967	2.2867	1.2962BC
Mean	0NS	1.4367	1.132	2.8693	0	1.5047	1.1653	2.5653	

LSD for Y x CS 0.1297

LSD for Y x CS x SA NS

Table 4.2.15 Interactive effect of winter water use efficiency(kg/ha/mm)as influenced by different soil additives and cropping systems during both years

Soil Additives	2010-11				2011-12				Mean
	CS1	CS2	CS3	CS4	CS1	CS2	CS3	CS4	
Control	12.613j-n	15.468bc	14.883b-f	15.007b-e	10.304r	12.958ijk	11.435opq	12.433j-n	13.138BC
Gypsum	13.961fgh	15.347b-e	14.554c-f	14.511def	10.845pqr	13.336hij	10.905pqr	11.951mno	13.176B
FYM	12.953i-l	15.326b-e	15.739b	14.874b-f	10.606qr	13.569ghi	12.184k-o	11.397opq	13.331AB
Compost	12.908i-l	12.99ijk	15.422bcd	14.549c-f	11.289opq	11.889mno	11.967mno	11.965mno	12.872C
Hydrogel	18.063a	13.214hij	14.645c-f	14.49efg	12.692i-m	12.031l-o	11.704nop	11.475opq	13.539A
Mean	14.100C	14.469BC	15.049A	14.686AB	11.147F	12.757D	11.639E	11.844E	

LSD for Y x CS 0.4128

LSD for Y x CS x SA 0.923

(13.61) followed by CS3 (13.34) and CS4 (13.26) while the lowest water use efficiency was recorded under CS1 (12.62). Water use efficiency for both the wheat seasons remained higher during 2010-11 (14.57) than 2011-12 (11.84). Meanwhile all the interactive effects viz. Y x CS, Y x SA, CS x SA and Y x CS x SA were statistically significant. Three way interactive effects have been presented in table 4.2.15. Farrell et al. (2013) worked on the effect of soil additives on the water retention and concluded that soil additives improves the water holding capacity and water use efficiency by modifying physical properties of the soil. Similarly, Raafat et al. (2012) worked on superabsorbent hydrogel and reported that these hydrogels have good swelling degree which might result to good water retention capacity and its application in agriculture field.The results are supported by work of El-Hady and Camilia (2006) who observed that the conditioners significantly increased water and fertilizers use efficiency of the plants. They concluded that applying 1 kg OM + 2g G to the plant pit was most suitable to get benefits of both types of soil conditioners without adverse effects on the production. Moreover, water use efficiency was improved by modifying existing cropping system compared to traditional one (Connor, 2004; Ma et al., 2008). Wu (2008) and Ma *et al.* (2008) in their findings concluded that increased water use efficiency and yield could be achieved by transition in the cropping system from Fallow to legume base. Keshavars et al., (2012) also concluded that application of super absorbent polymer resulted to increased WUE and highest conversion of drymatter to grain due to good translocation potential of crop because of availability of water even under water stress.Field experiments by Rana*et al*. (2006) studied the relative moisture utilization by maize (*Zea mays* L.) grown in a mixed or in a sole situation. An increase in water-use efficiency (WUE) was observed in intercropping systems.

4.3 AGRONOMIC PARAMETERS

4.3.1 Mungbean Agronomic Parameters

4.3.1.1 Mungbean seed yield

Mungbean seed yield was a significantly influenced variation by two years (Y), cropping systems (CS), soil additives (SA) and their interactions Y x SA and CS x SA (Appendix 15). The main effect of soil additives on Mungbean grain yield was highly significant. Highest seed yield was recorded for hydrogel (1022 kg/ha) while lowest seed yield recorded for control plots (928 kg/ha) (Table 4.3.1). Hydrogel additive recorded 10 % increase in mungbean seed yield over control.

Similarly, both the cropping systems differed potentially for mungbean seed yield. Sole mungbean produced more seed yield (1089 kg/ha) as compared to the Mungbean-Sorghum intercrop cropping system (863 kg/ha) which was 26 % higher than the intercrop. During second year i.e. 2011 mungbean seed yield was 11 % higher (1028 kg/ha) than the first year (923 kg/ha) was recorded during first year i.e. 2010.

The interactive effects (Y x SA and CS x SA) were highly significant for mungbean seed yield. Maximum mungbean seed yield (1071.8 kg/ha) was observed during 2011 for hydrogel while minimum seed yield (887.7 kg/ha) was recorded during 2010 for control treatment (Table 4.3.2). For interactive effect (Y x SA) during 2011 for hydrogel treatment there was 20 % increase in seed yield over control

Table 4.3.1 Mungbean yield and Yield attributes as influenced by different soil additives and cropping systems during both years

Year	Plant Height (cm)	No of Plants	No. of Pods	1000 Grain Weight (g)	No. of Branches	Biological Yield (kg ha^{-1})	Seed Yield (kg ha^{-1})	Harvest Index (%)
2010	43.28B	6.4367B	18.817B	30.296B	49.115B	2762.9B	923.5B	33.856A
2011	44.284A	6.6433A	19.254A	30.999A	53.449A	3399.1A	1028.5A	30.682B
LSD	0.1571	0.0517	0.0648	0.1102	1.3909	350.42	49.528	0.3573
Cropping System								
Sole	43.885A	6.5667A	19.081A	30.719A	57.110A	3317.8	1089.0A	33.327
Intercrop	43.678B	6.5133B	18.991B	30.576B	45.454B	2844.2	863.0B	31.211
LSD	0.01895	0.0434	0.064	0.0185	2.3918	NS	50.837	NS
Soil Additives								
Control	39.891E	5.81D	17.345E	27.923E	46.566D	2734.3D	928.1D	34.385A
Hydrogel	46.839A	7.15A	20.363A	32.787A	57.345A	3445.6A	1022.3A	30.152C
FYM	42.207D	6.16C	18.35D	29.545D	52.487B	3060.4BC	966.6C	32.27B
Compost	44.523C	6.73B	19.358C	31.166C	51.019B	3116.9B	991.2B	32.269B
Gypsum	45.449B	6.85B	19.762B	31.815B	48.992C	3047.9C	972.0C	32.268B
LSD	0.144	0.1346	0.0628	0.1009	1.8659	58.188	9.6307	0.1411
Interactions								
Y*CS	NS	NS	***	NS	NS	NS	NS	NS
Y*SA	NS	NS	NS	NS	NS	***	***	***
CS*SA	NS	NS	NS	NS	NS	***	***	NS
Y*CS*SA	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.3.2 Interactive effect of Y x SA on mungbean Seed Yield (kg ha^{-1})

Soil Additives	2010	2011	Mean
Control	887.7f	968.5cd	928.1D
Hydrogel	972.8c	1071.8a	1022.3A
FYM	907.2ef	1026b	966.6C
Compost	938.7de	1043.7ab	991.2B
Gypsum	911.3ef	1032.7b	972.0C
Mean	923.5B	1028.5A	
LSD for Y x SA	31.942		

Table 4.3.3 Interactive effect of CS x SA on mungbean seed yield (kg ha^{-1})

Soil Additives	Sole	Intercrop	Mean
Control	1060.0c	796.2f	928.1D
Hydrogel	1117.3a	927.3d	1022.3A
FYM	1084.8bc	848.3e	966.6C
Compost	1108.0ab	874.3e	991.2B
Gypsum	1075.0c	869.0e	972.0C
Mean	1089.0A	863.0B	
LSD for CS x SA	31.942		

treatment during 2010.

Higher mungbean seed yield (1117.3 kg/ha) recorded for sole mungbean cropping system with the application of hydrogel in the soil while lower mungbean seed yield (796.2 kg/ha) was observed under Mungbean-Sorghum intercrop cropping system for control plots (Table 4.3.3). Hydrogel treatment under sole mungbean cropping system got improved seed yield of mungbean upto 40 % than control under Mungbean-Sorghum intercrop cropping system.

Highest seed yield (1022 kg/ha) of mungbean due to hydrogel compared to control treatment (928 kg/ha) was due to ability of hydrogel to conserve soil water and make that water available to the crops at the time of need. Our results were at par with Widiatuti, (2008) and Green, (2004) who concluded that hydrogels have potential to increase crop yield under arid conditions of world. The hydrogels have potential to absorbs water four hundred times greater than the weight they have as reported by Monnig, (2005). With reference to cropping system maximum mungbean seed yield recorded for sole mungbean (1089 kg/ha) compared to Mungbean-Sorghum intercrop cropping system was due to no competition among plants when mungbean was planted alone compared to intercropping. Connor, (2004) in their findings concluded that efficiency of system could be increased by modifying cropping system but it was contradictory to our results.

4.3.1.2 Mungbean Plant Height

Mungbean plant height was a significantly influenced variation by two years (Y), cropping systems (CS) and soil additives (SA) (Appendix 16). The main effect of soil additives on Mungbean plant height was highly significant. Highest plant height was recorded for hydrogel treatment (46.84 cm) while lowest plant height (39.89 cm) recorded for control treatment (Table 4.3.1). Hydrogel soil additive recorded 17 % higher mungbean plant height compared to control treatment.

Similarly, both the cropping systems differed potentially for mungbean plant height. Maximum mungbean plant height was recorded for sole mungbean cropping system (43.86 cm) whereas minimum plant height (43.67 cm) was recorded under Mungbean-Sorghum intercrop cropping system. Under sole mungbean cropping system 1 % increase in mungbean plant height was recorded compared with Mungbean-Sorghum intercrop cropping system.

Both the years were also differed for mungbean plant height Maximum mungbean plant height (44.28 cm) was observed during second year i.e. 2011, while minimum plant height (43.28 cm) was recorded during first year i.e. 2010. The increase in plant height during second year (2011) than first year (2010) was 1.5 %.

The interactive effects (Y x CS, Y x SA, CS x SA and Y x CS x SA) were non-significant for mungbean plant height. Highest plant height due to hydrogel treatment (46.84 cm) compared to control was due to storage of soil water and its supply to the plants under stress. Similar results were reported by Kos and Le tan, (2003) in their findings and concluded that hydrogels increases the field capacity of soil. Among cropping system mungbean in sole cropping system performed well because of no competition for resources. Similar results were reported by Hauggaard-Nielsen and Jensen, (2001) and Zhang and Li (2003).

4.3.1.3 Mungbean Number of Plants Per Square Meter

Mungbean number of plants per square meter was a significantly influenced variation by two years (Y), cropping systems (CS) and soil additives (SA) (Appendix 17). The main effect of soil additives on Mungbean number of plants was highly significant. Highest number of plants was recorded for hydrogel treatment (7.15) while lowest number of plants (5.8) was recorded for control treatment (Table 4.3.1). Hydrogel additive recorded 23 % increase in number of plants over control.

Similarly, both the cropping systems varied considerably for mungbean number of plants. Maximum number of plants was recorded for sole mungbean cropping system (6.56) whereas minimum (6.51) number of plants was observed under Mungbean-Sorghum intercrop cropping system. Under sole mungbean cropping system 1 % increase in number of plants was recorded compared with Mungbean-Sorghum intercrop cropping system. Maximum mungbean number of plants (6.64) was observed during second year i.e. 2011, while minimum number of plants (6.43) was recorded during first year i.e. 2010. The increase in number of plants during second year (2011) than first year was 3 %.

The interactive effects (Y x CS, Y x SA, CS x SA and Y x CS x SA) were non-significant for mungbean number of plants per square meter. Highest number of plants under hydrogel treatments was because of their potential to stored soil water and improves nutritional status of soil. Kos and Le tan, (2003) in their findings concluded that hydrogels increases the field capacity of soil and improves soil structure and texture. Similarly, Koupai et al., (2008) in their results elaborated that hydrogels increase the soil water contents and can result in the significant reduction in the water demand of crops by alternatives sources like irrigation. However, among cropping system sole cropping system performed well because of no competition among plants for resources. Andersen et al., (2007) in their results concluded that intercropping is better than sole cropping as it helps in the utilization of resources effectively opposite to our findings.

4.3.1.4 Mungbean Number of Branches Per Square Meter

Mungbean number of branches per square meter was a significantly influenced variation by two years (Y), cropping systems (CS) and soil additives (SA) (Appendix 18). The main effect of soil additives on Mungbean number of branches was highly significant. Highest number of branches was recorded for hydrogel treatment (57.35) while lowest number of branches (46.56) was recorded for control treatment (Table 4.3.1). Hydrogel additive recorded 23 % increase in number of branches over control. Similarly, both the cropping systems varied considerably for mungbean number of branches per square meter. Maximum number of branches was recorded for sole mungbean cropping system (57.11) whereas minimum (45.45) number of branches was observed under Mungbean-Sorghum intercrop cropping system. Under sole mungbean cropping system 25 % increase in number of branches was recorded compared with Mungbean-Sorghum intercrop cropping system. Maximum mungbean number of branches (53.44) was observed during second year i.e. 2011, while minimum number of branches (49.11) was recorded during first year i.e. 2010. The increase in number of branches during second year (2011) than first year was 8 %.

The interactive effects (Y x CS, Y x SA, CS x SA and Y x CS x SA) were non-significant for mungbean number of branches per square meter. Highest number of branches due to hydrogel treatment was hydrogel potentials to absorb maximum water and make that water available to plants to increase their growth and developments

(Abedi-Koupai and Sohrab, 2004). Similarly, hydrogels is good option to grow plant under water limited conditions as concluded by Dehgan et al., (1994). Al-Sheik and Al-Darby (1996) elaborated that application of hydrogels increases water content of soil. However, among cropping system sole cropping system performed well because of no competition among plants for resources. Andersen et al., (2007) in their results concluded that intercropping is better than sole cropping as it helps in the utilization of resources effectively opposite to our findings.

4.3.1.5 Mungbean number of pods

Mungbean number of pods per plant was a significantly influenced variation by two years (Y), cropping systems (CS) soil additives (SA) and their interaction Y x CS (Appendix 19). The main effect of soil additives on number of pods per plant was highly significant. Highest mungbean number of pods was recorded for hydrogel treatment (20.36) while lowest (17.35) number of pods was recorded for control treatment (Table 4.3.1). Hydrogel soil additive recorded 17 % increase in number of pods over control. Similarly, both the cropping systems differed considerably for mungbean number of pods. Higher mungbean number of pods was observed for sole mungbean cropping system (19.08) whereas lower number of pods (18.99) was recorded under Mungbean-Sorghum intercrop cropping system. Under sole mungbean cropping system 1 % higher number of pods was recorded compared with Mungbean-Sorghum intercrop cropping system. Both the years (2010 and 2011) were also differed potentially for mungbean number of pods. Maximum mungbean number of pods (19.25) was recorded during 2011, while minimum number of pods (18.81) was recorded during 2010. During second year 2 % more number of pods was calculated than first growing year.

The interactive effects like Y x CS was significantly different for mungbean number of pods while the other interactive effects were non-significant. For Y x CS highest mungbean number of pods (19.30) was observed during 2011 under sole Mungbean-Wheat cropping system whereas, lowest mungbean number of pods (18.77) was recorded during 2010 from the plots where Mungbean-Sorghum was intercropped (Table 4.3.4). During 2011 under sole mungbean cropping system 3 % more mungbean number of pods were recorded than 2010 under Mungbean-Sorghum intercrop cropping system. Highest mungbean number of pods due to hydrogel was due to retention of water in the soil compared to control treatments. Similar results were reported by Dehgan et al., (1994) who concluded that hydrogels is good option to grow plant under water limited conditions. Meanwhile, Specht and Harvey-Jones, (2000) reported that plant survival rate was high due to hydrogels as they can retain water more in soil compared to control treatments which resulted to highest yield. The highest number of pods under sole mungbean cropping system compared to Mungbean-Sorghum intercrop cropping system was due to exhaustive nature of sorghum and competition among plants for resources. Similar to our findings Malai and Muthasankaranarayanan, (1999) concluded that intercropping resulted to competition for resources (light, water and nutrients) and reduced number of pods.

4.3.1.6 Mungbean thousand grains weight

Mungbean thousand grain weight (TGW) was a significantly influenced variation by two years (Y), cropping systems (CS) and soil additives (SA) (Appendix

20). The main effect of soil additives on mungbean TGW was highly significant. Highest mungbean TGW was recorded for hydrogel treatment (32.79 g) while lowest TGW was observed for control treatment (27.92 g) (Table 4.3.1). For hydrogel soil additive 17 % higher mungbean TGW was recorded over control. On the other hand both the cropping systems (Sole and Intercrop) were varied potentially for mungbean TGW. Higher TGW (30.72 g) was calculated for sole mungbean cropping system while lower TGW (30.57 g) was calculated under Mungbean-Sorghum intercrop cropping system. There was 1 % difference among both the cropping systems for mungbean thousand grain weight. Whereas, both the years (2010 and 2011) were differed considerably for mungbean TGW. Maximum mungbean TGW (30.99 g) was observed during 2010 while minimum TGW (30.29 g) was recorded during second year i.e. 2011. There was 11 % difference among both the years for mungbean m thousand grain yield.

The interactive effects (Y x CS, Y x SA, CS x SA and Y x CS x SA) were non-significant for mungbean thousand grain weight. Highest mungbean TGW due to hydrogel treatment (32.79 g) compared to control treatment (27.92 g) was due to potential of hydrogels to absorb maximum water and make that water available to plants to increase their growth and developments. Similar to our findings increased water content of soil was reported by Al-Sheik and Al-Darby (1996) due to application of hydrogels. Among cropping system highest TGW (30.72 g) calculated for sole mungbean cropping system might be due to optimum availability of resources for mungbean crop. Similar results were reported by Himayatullah (1991) who recorded decreased TGW due to intercropping might be due to competition of resources.

Table 4.3.4 Interactive effect of Y x CS on mungbean number of pods

Cropping System	2010	2011	Mean
Sole	18.862c	19.299a	19.081A
Intercrop	18.772d	19.209b	18.991B
Mean	18.817B	19.254A	
LSD	0.0522		

Table 4.3.5 Interactive effect of Y x SA on Mungbean biological yield

Soil Additives	**2010**	**2011**	**Mean**
Control	2487.8f	2980.7cde	2734.3D
Hydrogel	3098bcd	3793.2a	3445.6A
FYM	2622.5ef	3498.3ab	3060.4BC
Compost	2799.2def	3434.7ab	3116.9B
Gypsum	2807.2def	3288.7bc	3047.9C
Mean	2762.9B	3399.1A	
LSD	407.22		

Table 4.3.6 Interactive effect of CS x SA on Mungbean biological yield

Soil Additives	Sole	Intercrop	Mean
Control	3018bcd	2450.5e	2734.3D
Hydrogel	3635.0a	3256.2abc	3445.6A
FYM	3316.8ab	2804de	3060.4BC
Compost	3365.8ab	2868cd	3116.9B
Gypsum	3253.5abc	2842.3de	3047.9C
Mean	3317.8	2844.2	
LSD	407.22		

Table 4.3.7 Interactive effect of Y x SA on mungbean harvest index

Soil Additives	2010	2011	Mean
Control	35.972a	32.798a-d	34.385A
Hydrogel	31.738b-e	28.567e	30.152C
FYM	34.915ab	29.625de	32.27B
Compost	33.857abc	30.682cde	32.269B
Gypsum	32.798a-d	31.738b-e	32.268B
Mean	33.856A	30.682B	
LSD Y x SA	3.5264		

4.3.1.7 Mungbean Biological Yield

Mungbean biological yield was a significantly influenced variation by two years (Y), cropping systems (CS), soil additives (SA) and their interactions (Y x SA and CS x SA) (Appendix 21). The main effect of soil additives on mungbean biological yield was highly significant. Highest mungbean biological yield was recorded for hydrogel treatment (3445.6 kg/ha) while lowest biomass yield (2734.3 kg/ha) was recorded for control treatment (Table 4.3.1). Hydrogel soil additive recorded 26 % higher mungbean biological yield than control treatment. Both the cropping systems (Sole and Intercrop) were not varied potentially for mungbean biomass accumulation. Whereas, both the years (2010 and 2011) considerably differed for mungbean biological yield. Maximum mungbean biological yield (3399 kg/ha) was observed during second year i.e. 2011, while minimum biological yield (2763 kg/ha) was recorded during first year i.e. 2010. The increase in biological yield during second year (2011) than first year (2010) was 23%.

The interactive effects like Y x SA and CS x SA were significantly different for mungbean biological yield while other interactive effects were non-significant. Maximum mungbean biological yield (3793 kg/ha) was observed during 2011 from the plots where hydrogel was applied whereas, minimum biological yield (2487 kg/ha) was recorded during 2010 under control treatment (Table 4.2.5). For interactive effect (Y x SA) during 2011 for hydrogel treatment there was 34 % increase in biological yield over control treatment during 2010. Likewise, highest mungbean biomass (3635 kg/ha) was observed under sole mungbean cropping system where hydrogel was used whereas, lowest mungbean biological yield (2450 kg/ha) was recorded under control treatment in the plots where Mungbean-Sorghum was intercropped (Table 4.3.6). Hydrogel treatment under sole sorghum cropping system got 32 % higher mungbean biological yield than control treatment under Mungbean-Sorghum intercrop cropping system.

Highest biological yield of mungbean under hydrogel treatment was due to highest moisture availability to the plant. The moisture furthermore resulted in the synthesis of biomass by the process of photosynthesis compared to control treatments where moisture becomes limiting factor resulting to lowest biomass. The work of Huang and Petrovic, (1994) confirmed the use of super absorbent polymers to conserve soil water. Inclusion of legume crop like mungbean in the system might result to increased N contents of soil which might increases yield of intercropped crop like sorghum. However, in our findings highest biological yield under sole cropping compared to control was due to competition of resources which is contradictory to the findings of Kirkegaard et al. (2008) who concluded that intercrop with legumes results to better growth compared to monoculture.

4.3.1.8 Mungbean Harvest Index

Mungbean harvest index was a significantly influenced variation by two years (Y), cropping systems (CS), soil additives (SA) and their interactions (Y x SA and CS x SA) (Appendix 22). The main effects of soil additives on mungbean harvest index were varied potentially. Highest mungbean harvest index was recorded for control treatment (34.38 %) while lowest harvest index (30.15 %) was recorded for hydrogel treatment (Table 4.2.1). There was 14 % difference among control and hydrogel treatments for mungbean harvest index. On the other hand both the cropping systems

(Sole and Intercrop) were statistically non-significant for mungbean harvest index. Whereas, both the years were varied significantly for mungbean harvest index. Maximum mungbean harvest index (33.85 %) was observed during first year i.e. 2010, while minimum harvest index (30.68 %) was recorded during second year of research i.e. 2011. The increase in harvest index during first year (2010) than the second year (2011) was 10 %.

The interactive effect viz Y x SA was differed significantly for mungbean harvest index while other interactive effects were non-significant. Maximum mungbean harvest index (35.97 %) was calculated during 2010 under control treatment whereas, minimum harvest index (28.56 % kg/ha) was recorded during 2011 under hydrogel treatment (Table 4.3.7). For interactive effect (Y x SA), during 2010 for control treatment there was 26 % higher harvest index compared to hydrogel treatment during 2011. Highest mungbean harvest index under control treatment due to hydrogel was due to excessive vegetative growth of plants which was similar to the findings of

Keshavars et al., (2012) who concluded that application of super absorbent polymer resulted to increased WUE and highest conversion of drymatter to grain due to good translocation potential of crop.

4.3.2 Sorghum Agronomic Parameters

4.3.2.1 Sorghum number of plants/m^2

Sorghum number of plants was significantly influenced variation by two years (Y), cropping systems (CS) and soil additives (SA) (Appendix 23). The main effect of soil additives on sorghum no of plants per square meter was highly significant. Highest sorghum number of plants was recorded for hydrogel (7.14) while lowest number of plants was recorded for control treatment (5.81) (Table 4.3.8). Hydrogel soil additive recorded 23 % increase in sorghum number of plants over control. Similarly, both the cropping systems differed potentially for sorghum number of plants. Maximum sorghum number of plants was observed for sole sorghum cropping system (6.56) whereas minimum number of plants (6.51) was recorded under Mungbean-Sorghum intercrop cropping system. Under sole sorghum cropping system 1 % increase in sorghum number of plants was recorded compared with Mungbean-Sorghum intercrop cropping system. Similarly, both the years varied potentially for sorghum number of plants per square meter. Maximum sorghum number of plants (6.64) was observed during second year i.e. 2011, while minimum sorghum number of plants (6.43) was recorded during first year i.e. 2010. The increase in sorghum number of plants during second year (2010) than first year was 3 %.

The interactive effects (Y x CS, Y x SA, CS x SA and Y x CS x SA) were non-significant for sorghum number of plants per meter square.

The highest sorghum number of plants due to hydrogel might be due its potential to conserve soil water. This conservation might resulted to good crop stand and number of plants compared to control treatments. Similar, results were reported by El-Hady and Abo-Sedera, (2006) who concluded that addition of hydrogel in the form of soil amendments resulted to increased water-holding capacity and increased availability of water to plants. Furthermore, this helps in the improvement of soil structure, reduced compaction and makes nutrients available to the crop (Hickman and Whitney, 1998). Therefore, good availability of water and nutrients due to hydrogel resulted to higher number of plants in our study.

Table 4.3.8 Sorghum yield and yield attributes as influenced by different soil additives and cropping systems during both years

Year	Sorghum Grain Yield	BY	HI	No of Plants	Panicle Length	TGW	Plant Height
2010	771.43A	2969.9B	26.072A	6.43B	14.107A	25.106A	130.93A
2011	762.93B	3196.8A	23.986B	6.64A	13.503B	24.045B	111.93B
LSD	5.7297	147.32	0.0698	0.0657	0.1004	0.2028	3.0344
Cropping System							
Sole	856.00A	3281.9	26.247	6.56A	14.530A	25.869A	127.82A
Intercrop	678.37B	2884.8	23.811	6.51B	13.080B	23.282B	115.04B
LSD	41.049	NS	NS	0.04	0.1252	0.2255	0.8612
Soil Additives							
Control	726.75C	2787.9C	26.112A	5.81D	11.942E	21.227E	110.40D
Hydrogel	795.08A	3358.2A	23.816C	7.14A	14.650A	26.076A	129.46A
FYM	768.42B	3086.9B	25.045B	6.16C	13.817D	24.612D	122.65B
Compost	773.08B	3093.8B	25.083B	6.73B	14.233C	25.344C	121.58C
Gypsum	772.58B	3089.9B	25.088B	6.85B	14.383B	25.618B	123.06B
LSD	7.5533	46.646	0.083	0.13	0.0696	0.1292	0.563
Interactions							
Y*CS	NS	NS	NS	NS	NS	NS	***
Y*SA	***	***	***	NS	***	***	***
CS*SA	***	***	***	NS	***	***	***
Y*CS*SA	NS	NS	NS	NS	NS	NS	NS

Intercropping with legumes crop have shown great potential to increase growth of non-legume crop but here in our case results were different from earlier findings who emphasized on use of intercropping with legumes. The sole sorghum crop depicted highest number of plants might be due to availability of water under rainfed conditions while in intercrop it might decreases its number of plants due to competition with other crops. The results were opposite to the findings of Andersen et al., 2007 who concluded that intercropping is better than sole cropping as it helps in the utilization of resources effectively. Similar results were reported by Hauggaard-Nielsen and Jensen, (2001) and Zhang and Li (2003).

4.3.2.2 Sorghum plant height

Sorghum plant height was significantly influenced variation by two years (Y), cropping systems (CS), soil additives (SA) and their interactions (Y x SA, Y x CS and CS x SA) (Appendix 24). The main effect of soil additives on sorghum plant height was highly significant. Highest sorghum plant height was recorded for hydrogel treatment (126.46 cm) while lowest plant height was recorded for control treatment (110.4 cm) (Table 4.3.8). Hydrogel soil additive recorded 17 % increase in sorghum plant height over control. Similarly, both the cropping systems differed potentially for sorghum plant height. Maximum sorghum plant height was recorded for sole sorghum cropping system (127.82 cm) whereas minimum plant height (115.04 cm) was recorded under Mungbean-Sorghum intercrop cropping system. Under sole sorghum cropping system 11 % increase in sorghum plant height was recorded compared with Mungbean-Sorghum intercrop cropping system. Whereas, both the years (2010 and

2011) varied considerably for sorghum plant height. Maximum sorghum plant height (130.93 cm) was recorded during 2010, while minimum plant height (111.93 cm) was recorded during 2011. The increase in plant height during 2010 than 2011 was 19%.

The interactive effects like Y x CS, Y x SA and CS x SA were differed significantly for sorghum plant height while three way interactive effects (Y x CS x SA) was non-significant. Maximum plant height (137.82 cm) was recorded during 2010 under sole sorghum cropping system while minimum plant height (106.04 cm) was recorded during 2011 under Mungbean-Sorghum intercrop cropping system (Table 4.3.9). Similarly, for Y x SA Maximum sorghum plant height (137.63 cm) was observed during 2010 from the plots where hydrogel was applied whereas, minimum plant height (106.53 cm) was recorded during 2011 under control treatment (Table 4.3.10). For interactive effect (Y x SA) during 2010 for hydrogel treatment there was 29 % increase in plant height over control treatment during 2011. In the same way highest sorghum plant height (136.66 cm) was observed under sole sorghum cropping system where hydrogel was used whereas, lowest sorghum plant height (104.58 cm) was recorded under control treatment in the plots where Mungbean-Sorghum was intercropped (Table 4.3.11). Hydrogel treatment under sole sorghum cropping system got 30 % higher sorghum plant height than control treatment under Mungbean-Sorghum intercrop cropping system.

Plant height is component which is significantly been affected due to deficiency of soil water. In our present studies sorghum height was increased due to the availability of soil water. Hydrogel as hydrophilic properties helped the soil to make water available to crop at critical growth stages compared to treatments where

Table 4.3.9Interactive effect of Y x CS on Sorghum Plant Height

Cropping System	**2010**	**2011**	**Mean**
Sole	137.82a	117.83c	127.82A
Intercrop	124.03b	106.04d	115.04B
Mean	130.93A	111.93B	
LSD	0.7131		

Table 4.3.10Interactive effect of Y x SA on Sorghum Plant Height

Soil Additives	**2010**	**2011**	**Mean**
Control	114.22f	106.58i	110.40D
Hydrogel	137.63a	121.28e	129.46A
FYM	136.3b	109.00h	122.65B
Compost	132.3d	110.87g	121.58C
Gypsum	134.18c	111.93g	123.06B
Mean	130.93A	111.93B	
LSD	1.1275		

hydrogel was not applied. Hydrogel, hydrophilic nature has been proved earlier by Abedi-Koupai, (2008) and he concluded that hydrogel could be good source to conserve soil water. Simialrly hydrogel improves soil water holding capacity, minimizes evapotranspiration and allow plants to survive under water stress (Chirino et al., 2008). The benefit of hydrogels to improve soil water contents were also confirmed by Landis (2012) who concluded that hydrogel could be good source to mitigate dry seasons. Meanwhile soil amendments in the form of hydrogels, FYM and tank soil improves the soil structure and makes the nutrients available resulted to good growth of plants. The availability of nutrients due to hydrogel was confirmed by Asghari et al., (2011) and Narjary et al., (2012) and they concluded that hydrogels have potential to improve soil structure and texture resulting to good infiltration rate and availability of nutrients.

4.3.2.3 Sorghum panicle length

Sorghum panicle length was significantly influenced variation by two years (Y), cropping systems (CS), soil additives (SA) and their interactions (Y x SA and CS x SA) (Appendix 25). The main effect of soil additives on sorghum panicle length was highly significant. Highest sorghum panicle length was recorded for hydrogel treatment (14.65 cm) while lowest panicle length was recorded for control treatment (11.94 cm) (Table 4.3.8). Hydrogel soil additive recorded 23 % increase in sorghum panicle length over control. Similarly, both the cropping systems differed considerably for sorghum panicle length. Higher sorghum panicle length was recorded for sole sorghum cropping system (14.53 cm) whereas lower panicle length (13.08 cm) was recorded under Mungbean-Sorghum intercrop cropping system. Under sole sorghum cropping system 11 % higher panicle length was recorded compared with Mungbean-Sorghum intercrop cropping system. Whereas, both the years (2010 and 2011) were differed potentially for sorghum panicle length. Maximum sorghum panicle length (14.11 cm) was recorded during 2010, while minimum panicle length (13.5 cm) was recorded during 2011. During first year 4 % more panicle length was calculated than the second growing year.

The interactive effects like Y x SA and CS x SA were varied significantly for sorghum plant panicle length while the other interactive effects were non-significant. For Y x SA maximum sorghum panicle length (14.81 cm) was observed during 2010 from the plots where hydrogel was applied whereas, minimum panicle length (11.53 cm) was recorded during 2011 under control treatment (Table 4.3.12). For interactive effect (Y x SA) during 2010 under hydrogel treatment there was 28 % higher panicle length than control treatment during 2011. In the same way highest sorghum panicle length (15.42 cm) was observed under sole sorghum cropping system where hydrogel was used whereas, lowest sorghum panicle length (11.31 cm) was recorded under control treatment in the plots where Mungbean-Sorghum was intercropped (Table 4.3.13). Hydrogel treatment under sole sorghum cropping system got 36 % more sorghum panicle length than control treatment under Mungbean-Sorghum intercrop cropping system.

Soil additives affected sorghum panicle length significantly and maximum response was obtained due to hydrogel treatment and it might be due to ability of hydrogels to aggregate soil particles resulting to storage of water and its availability to plants at the time of need. Our results were at par with the findings of Shainberg et al.,

(1990) and Yangyuoru et al., (2006) who concluded that hydrogels acts as soil conditioners and improves plant growth and development under dry conditions. Similarly, Allahdadietal., (2005) and Sharma, (2004) concluded that hydrogel makes water available in the root zone resulting to good establishment of crop and improvements in the yield related parameters.

The cropping system affected panicle length significantly but it was not at par with earlier findings as in our studies the highest panicle length was obtained under sole cropping compared to intercropping. Chandra et al., (2009) concluded that intercropping is best way to minimize erosion and increased yield in rainfed regions of world. Similarly, according to Chandra, (2007) it is more cost effective compared to sole cropping. Meanwhile, intercropping crops with legumes resulted to higher resources use efficiency as concluded by Maikhuri et al., (1997). However, our result might be different due to reasons as legume crops beneficial effects starts after certain years of practice compared to one year.

The interactive effects like Y x SA and CS x SA were significantly showing effect on panicle length and it might be due to good response of soil additives in the improvements of soil structure resulted to higher panicle length under interactions. Since soil quality is improved by aggregate stability, strength, fluid transmission, and storage characteristics in the crop root zone therefore, soil additives could be potential options to improve soil health and crop yield. Similar results were reported by El-Hady et al. (2000) who concluded that soil additives helps in the maintenance of soil health and improvement of crop growth and yield. Simialrly, it was earlier concluded by El-Hady et al. (2000) and El- Hady and Camilia (2006) that addition of organic materials

Table 4.3.11 Interactive effect of CS x SA on Sorghum Plant Height

Soil Additives	Sole	Intercrop	Mean
Control	116.22ef	104.58g	110.40D
Hydrogel	136.55a	122.37d	129.46A
FYM	128.83bc	116.47e	122.65B
Compost	127.98c	115.18f	121.58C
Gypsum	129.53b	116.58e	123.06B
Mean	130.93A	111.93B	
LSD	1.1275		

Table 4.3.12Interactive effect of Y x SA on Sorghum panicle length

Soil Additives	**2010**	**2011**	**Mean**
Control	12.35f	11.533g	11.942E
Hydrogel	14.817a	14.483c	14.650A
FYM	14.6b	13.033e	13.817D
Compost	14.283d	14.183d	14.233C
Gypsum	14.483c	14.283d	14.383B
Mean	14.107A	13.503B	
LSD	0.1141		

in combination with hydrogels resulted more economical compared to application of hydrogel alone. Since hydrogel are very expensive and for raising agronomic crops its economically viable to use them with FYM.

4.3.2.4 Sorghum Thousand Grains Weight

Sorghum thousand grain weight (TGW) was significantly influenced variation by two years (Y), cropping systems (CS), soil additives (SA) and their interactions (Y x SA and CS x SA) (Appendix 26). The main effect of soil additives on sorghum TGW was highly significant. Highest sorghum TGW was recorded for hydrogel treatment (26.08 g) while lowest TGW was observed for control treatment (21.22 g) (Table 4.3.8). Hydrogel soil additive recorded 22 % increase in sorghum TGW over control. On the other hand both the cropping systems (Sole and Intercrop) were varied potentially for sorghum TGW. Higher TGW (25.86 g) was calculated for sole cropping system while lower TGW (23.28 g) was calculated under Mungbean-Sorghum intercrop cropping system. There was 11 % difference among both the cropping systems for sorghum thousand grain weight. Whereas, both the years (2010 and 2011) varied considerably for sorghum TGW. Maximum sorghum TGW (25.10 g) was observed during 2010 while minimum TGW (24.04 g) was recorded during second year i.e. 2011. There was 4 % difference among both the years for sorghum thousand grain yield.

The interactive effects like Y x SA and CS x SA were differed potentially for sorghum thousand grain yield while other interactive effects were non-significant. Maximum sorghum TGW (26.35 g) was observed during 2010 from the plots where hydrogel was applied whereas, minimum sorghum TGW (20.49 g) was recorded during 2011 under control treatment (Table 4.3.14). For interactive effect (Y x SA) during 2010 for hydrogel treatment there was 28 % increase in TGW over control treatment during 2010. Likewise, highest sorghum TGW (27.45 g) was observed under sole sorghum cropping system in the plots where hydrogel was used whereas, lowest sorghum TGW (20.11 g) was recorded under control treatment in the plots where Mungbean-Sorghum was intercropped (Table 4.3.15). Hydrogel treatment under sole sorghum cropping system got 36 % higher sorghum TGW than control treatment under Mungbean-Sorghum intercrop cropping system.

Soil additives increased sorghum TGW compared to control and increase was high due to hydrogel soil additive and it remained 22 % higher than control. The results were in line with Dehgan et al., (1994) who concluded that hydrogels is good option to grow plant under water limited conditions. They concluded that hydrogels enhances drought tolerance of crop under water stress resulted to highest thousand grain weight compared to control treatments. Similarly, increase water content of soil was reported by Al-Sheik and Al-Darby (1996) due to application of hydrogels. They further elaborated that increased water status of soil helps in the establishment of crops effectively resulting to higher yield. Meanwhile, Specht and Harvey-Jones, (2000) reported that plant survival rate was high due to hydrogels as they can retain water more in soil compared to control treatments. Viero et al. (2000) concluded that crop growth and yield could be improved by the application of hydrogels as soil amendments. Abedi-Koupai and Sohrab, (2004) was of the view that hydrogels have potentials to absorb maximum water and make that water available to plants to increase their growth and developments.

Table 4.3.13 Interactive effect of CS x SA on Sorghum panicle length

Soil Additives	**Sole**	**Intercrop**	**Mean**
Control	12.567i	11.317j	11.942E
Hydrogel	15.417a	13.883e	14.650A
FYM	14.55d	13.083h	13.817D
Compost	14.983c	13.483g	14.233C
Gypsum	15.133b	13.633f	14.383B
Mean	14.530A	13.080B	
LSD	0.1141		

Table 4.3.14Interactive effect ofY x SA on Sorghum Thousand Grain Weight

Soil Additives	**2010**	**2011**	**Mean**
Control	21.959e	20.495f	21.227E
Hydrogel	26.350a	25.801b	26.076A
FYM	25.984b	23.24d	24.612D
Compost	25.435c	25.252c	25.344C
Gypsum	25.801b	25.435c	25.618B
Mean	25.106A	24.045B	
LSD	0.2107		

Table 4.3.15Interactive effect of CS x SA on Sorghum Thousand Grain Weight

Soil Additives	Sole	Intercrop	Mean
Control	22.344i	20.109j	21.227E
Hydrogel	27.448a	24.703e	26.076A
FYM	25.907d	23.317h	24.612D
Compost	26.678c	24.01g	25.344C
Gypsum	26.967b	24.27f	25.618B
Mean	25.869A	23.282B	
LSD	0.2107		

Table 4.3.16Interactive effect of Y x SA on Sorghum Grain yield

Soil Additives	2010	2011	Mean
Control	721.17d	732.33d	726.75C
Hydrogel	804.67a	785.5ab	795.08A
FYM	778.0bc	758.83c	768.42B
Compost	777.0bc	769.17bc	773.08B
Gypsum	776.3bc	768.83bc	772.58B
Mean	771.43A	762.93B	
LSD	23.83		

The cropping system affected TGW significantly but highest TGW was recorded for sole cropping compared to intercropping. The results were in contradictory to earlier findings who concluded that intercropping with legumes crops increased crop yield by improving soil nutritional status. They also concluded that with intercropping farmers can have more crops on a unit piece of land resulting to highest resource use efficiency compared to sole cropping. Meanwhile, intercropping also resulted to nitrogen availability to companion crop and increased soil organic matter (Getachew et al., 2007). Furthermore, Wortmann et al., (2009) reported inacresed crop yield due to intercropping. However, our results were at par with Himayatullah (1991) who recorded decreased crop yield due to intercropping. The detrimental effect of intercropping on TGW in our studies might be due to completion for resources (light, water and nutrients) resulted to reduced TGW. Similar results were concluded by Malai and Muthasankaranarayanan, (1999) who sated that sorghum yield remained high under sole compared to intercropping. The results were also in relevant to the conclusion of Rashid et al., (2004) who reported highest grain yield of sorghum when planted sole compared to intercropping.

4.3.2.5 Sorghum grain yield

Sorghum grain yield was significantly influenced variation by two years (Y), cropping systems (CS), soil additives (SA) and their interactions (Y x SA and CS x SA) (Appendix 27). The main effect of soil additives on sorghum grain yield was highly significant. Highest sorghum grain yield was recorded for hydrogel treatment (795.08 kg/ha) while lowest grain yield was recorded for control treatment (726.75

kg/ha) (Table 4.3.8). Hydrogel soil additive recorded 9 % increase in sorghum grain yield over control. Both the cropping systems (Sole and Intercrop) were differed considerably for sorghum grain yield. Maximum sorghum grain yield was recorded for sole sorghum cropping system (856 kg/ha) whereas minimum grain yield (678 kg/ha) was recorded under Mungbean-Sorghum intercrop cropping system. Under sole sorghum cropping system 10 % increase in sorghum grain yield was calculated compared with Mungbean-Sorghum intercrop cropping system. Similarly, both the years varied potentially for sorghum grain yield. Maximum sorghum grain yield (771.43 kg/ha) was observed during second year i.e. 2011, while minimum grain yield (762.93 kg/ha) was recorded during first year i.e. 2010. The increase in grain yield during second year (2011) than first year (2010) was 1%.

The interactive effects like Y x SA and CS x SA were highly significant for sorghum grain yield while other interactive effects were non-significant. Maximum sorghum grain yield (804.67 kg/ha) was observed during 2010 where hydrogel was applied whereas, minimum grain yield (721 kg/ha) was recorded during 2010 under control treatment (Table 4.3.16). For interactive effect (Y x SA) during 2010 for hydrogel treatment there was 12 % increase in grain yield over control treatment during 2010. Likewise, highest sorghum grain yield (869 kg/ha) was observed under sole sorghum cropping system where hydrogel was used whereas, lowest sorghum grain yield (623 kg/ha) was recorded in the plots where Mungbean-Sorghum was intercropped (Table 4.3.17). Hydrogel treatment under sole sorghum cropping system got 40 % higher sorghum grain yield than control treatment under Mungbean-Sorghum intercrop cropping system.

Highest sorghum grain yield under hydrogel treatment (795.08 kg/ha) might be potential of hydrogel to absorb water and improves soil structure. The highest absorption of water was due to hydrophilic nature of these treatments which resulted to highest moisture availability to the plant. The moisture furthermore resulted in the synthesis of biomass by the process of photosynthesis compared to control treatments where moisture becomes limiting factor resulting to lowest biomass and grain yield. The work of Huang and Petrovic, (1994) confirmed the use of super absorbent polymers to conserve soil water. Meanwhile, Zhang et al., (2007) concluded that hydrogels have grate potential to increase plant growth and production indirectly by storing soil water and reclamation of soil. Our results were similar to Johnson and Leah, (1990) who concluded that hydrogel are good source to store water and have potential to improve rainfed agriculture. Meanwhile, Specht and Harvey-Jones, (2000) reported that plant survival rate was high due to hydrogels as they can retain water more in soil compared to control treatments. Viero et al. (2000) concluded that crop growth and yield could be improved by the application of hydrogels as soil amendments. Abedi-Koupai and Sohrab, (2004) was of the view that hydrogels have potentials to absorb maximum water and make that water available to plants to increase their yield.

Since maximum sorghum grain yield was recorded for sole sorghum cropping system (856 kg/ha) whereas minimum grain yield (678 kg/ha) was recorded under Mungbean-Sorghum intercrop cropping system. Therefore results were in contradictory to earlier workers who emphasised on the use of intercropping. They reported that inclusion of legume crop like mungbean in the system might result to increased N contents of soil which might increases yield of intercropped crop like sorghum. The results were in contrast to Kirkegaard et al. (2008) who concluded that intercrop with legumes results to better growth compared to monoculture. However, results were in line with Malai and Muthasankaranarayanan, (1999) who sated that sorghum yield remained high under sole compared to intercropping. The results were also in relevant to the conclusion of Rashid et al., (2004) who reported highest grain yield of sorghum when planted sole compared to intercropping. Meanwhile, earlier studies reported that negative impacts of exhaustive crops like sorghum could be minimized by intercropping with legume crop (Norwood, 2000). The interactive effect of cropping system and soil additives revealed that additives performance was better under sole cropping. This might be due to good water absorption potential of additives and its availability to crop at the time of need. The use of soil additives like crop residuals, mulch plants, waste, litter, straw, stubble, gypsum, compost, FYM and hydrogel have been proved earlier as potential source to conserve soil water and increase crop growth and yield (Silberbush et al., 1993).

4.3.2.6 Sorghum biological yield

Sorghum biological yield was significantly influenced variation by two years (Y), cropping systems (CS), soil additives (SA) and their interactions (Y x SA and CS x SA) (Appendix 28). The main effect of soil additives on sorghum biological yield was highly significant. Highest sorghum biological yield was recorded for hydrogel treatment (3358.2 kg/ha) while lowest biomass yield was recorded for control treatment (2787.9 kg/ha) (Table 4.3.1). Hydrogel soil additive recorded 20 % increase in sorghum biological yield over control. On the other hand both the cropping systems

(Sole and Intercrop) were not varied potentially for sorghum biomass accumulation. Whereas, both the years (2010 and 2011) varied considerably for sorghum biological yield. Maximum sorghum biological yield (3196.8 kg/ha) was observed during second year i.e. 2011, while minimum biological yield (2969 kg/ha) was recorded during first year i.e. 2010. The increase in biological yield during second year (2011) than first year (2010) was 8%.

The interactive effects like Y x SA and CS x SA were varied potentially for sorghum biological yield while other interactive effects were non-significant. Maximum sorghum biological yield (3475 kg/ha) was observed during 2011 from the plots where hydrogel was applied whereas, minimum biological yield (2663 kg/ha) was recorded during 2010 under control treatment (Table 4.3.18). For interactive effect (Y x SA) during 2011 for hydrogel treatment there was 30 % increase in biological yield over control treatment during 2010. Likewise, highest sorghum biomass (3515 kg/ha) was observed under sole sorghum cropping system where hydrogel was used whereas, lowest sorghum biological yield (2549 kg/ha) was recorded under control treatment in the plots where Mungbean-Sorghum was intercropped (Table 4.3.19). Hydrogel treatment under sole sorghum cropping system got 38 % higher sorghum biological yield than control treatment under Mungbean-Sorghum intercrop cropping system.

Highest biological yield of sorghum under hydrogel treatment was due to hydrophilic nature of these treatments which resulted to highest moisture availability to the plant. The moisture furthermore resulted in the synthesis of biomass by the process of photosynthesis compared to control treatments where moisture becomes

Table 4.3.17Interactive effect of CS x SA on Sorghum Grain yield

Soil Additives	Sole	Intercrop	Mean
Control	830.50b	623.00e	726.75C
Hydrogel	869.17a	721.00c	795.08A
FYM	862.83a	674.00d	768.42B
Compost	864.50a	681.67d	773.08B
Gypsum	853.0ab	692.17d	772.58B
Mean	856.00A	678.37B	

LSD

Table 4.3.18Interactive effect ofY x SA on Sorghum Biological yield

Soil Additives	**2010**	**2011**	**Mean**
Control	2663e	2912.8cde	2787.9C
Hydrogel	3241.2abc	3475.2a	3358.2A
FYM	2906.3de	3267.5ab	3086.9B
Compost	2979.2b-e	3208.5a-d	3093.8B
Gypsum	3060bcd	3119.8bcd	3089.9B
Mean	2969.9B	3196.8A	

LSD Y x SA 334.57

limiting factor resulting to lowest biomass. The work of Huang and Petrovic, (1994) confirmed the use of super absorbent polymers to conserve soil water. Meanwhile, Zhang et al., (2007) concluded that hydrogels have grate potential to increase plant growth and production indirectly by storing soil water and reclamation of soil. Our results were similar to Johnson and Leah, 1990 who concluded that hydrogel are good source to store water and have potential to improve rainfed agriculture.

Inclusion of legume crop like mungbean in the system might result to increased N contents of soil which might increases yield of intercropped crop like sorghum. In case of intercropping highest biological yield recorded for sorghum compared to sole cropping. The results were in line with Kirkegaard et al. (2008) who concluded that intercrop with legumes results to better growth compared to monoculture. Meanwhile negative impacts of exhaustive crops like sorghum could be minimized by intercropping with legume crop (Norwood, 2000). The interactive effect of cropping system and soil additives revealed that additives performance was better under sole cropping. This might be due to good water absorption potential of additives and its availability to crop at the time of need. The use of soil additives like crop residuals, mulch plants, waste, litter, straw, stubble, gypsum, compost, FYM and hydrogel have been proved earlier as potential source to conserve soil water (Silberbush et al., 1993) and increase crop growth and yield.

4.3.2.7 Sorghum harvest index

Sorghum harvest index was significantly influenced variation by two years (Y), soil additives (SA) and their interactions (Y x SA and CS x SA) (Appendix 29). The main effects of soil additives on sorghum harvest index were varied potentially. Highest sorghum harvest index was recorded for control treatment (26.11 %) while lowest harvest index was recorded for hydrogel treatment (23.82 %) (Table 4.3.8). There was 10 % difference among control and hydrogel treatments for sorghum harvest index. On the other hand both the cropping systems (Sole and Intercrop) were not varied potentially for sorghum harvest index. Whereas, both the years (2010 and 2011) varied significantly for sorghum harvest index. Maximum sorghum harvest index (26.07 %) was observed during first year i.e. 2010, while minimum harvest index (23.98 %) was recorded during second year of research i.e. 2011. The increase in harvest index during first year (2010) than the second year (2011) was 9 %.

The interactive effects viz Y x SA and CS x SA were differed significantly for sorghum harvest index while other interactive effects were non-significant. Maximum sorghum harvest index (27.04 %) was calculated during 2010 under control treatment whereas, minimum harvest index (22.71 % kg/ha) was recorded during 2011 under hydrogel treatment (Table 4.3.20). For interactive effect (Y x SA), during 2010 for control treatment there was 19 % increase in harvest index compared to hydrogel treatment during 2011. Likewise, highest sorghum harvest index (27.55 %) was observed under sole sorghum cropping system under control treatment whereas, lowest sorghum harvest index (22.78 %) was recorded in the plots where hydrogel was used under Mungbean-Sorghum intercrop cropping system (Table 4.3.21). For control treatment under sole sorghum cropping system 21 % higher sorghum harvest index was calculated than hydrogel treatment under Mungbean-Sorghum intercrop cropping system.

Table 4.3.19Interactive effect of CS x SA on Sorghum Biological yield

Soil Additives	**Sole**	**Intercrop**	**Mean**
Control	3026.7bc	2549.2d	2787.9C
Hydrogel	3515.5a	3200.8abc	3358.2A
FYM	3305.2ab	2868.7cd	3086.9B
Compost	3301.8ab	2885.8c	3093.8B
Gypsum	3260.5ab	2919.3c	3089.9B
Mean	3281.9NS	2884.8	
LSD CS x SA	334.57		

Table 4.3.20Interactive effect ofY x SA on Sorghum Harvest Index

Soil Additives	**2010**	**2011**	**Mean**
Control	27.043a	25.182a-d	26.112A
Hydrogel	24.923bcd	22.708e	23.816C
FYM	26.805ab	23.285de	25.045B
Compost	26.132abc	24.035cde	25.083B
Gypsum	25.455abc	24.722b-e	25.088B
Mean	26.072A	23.986B	
LSD	2.1018		

Table 4.3.21Interactive effect of CS x SA on Sorghum Harvest Index

Soil Additives	Sole	Intercrop	Mean
Control	27.555a	24.67bc	26.112A
Hydrogel	24.848bc	22.783c	23.816C
FYM	26.282ab	23.808c	25.045B
Compost	26.298ab	23.868c	25.083B
Gypsum	26.25ab	23.927c	25.088B
Mean	26.247	23.811	

LSD 2.1018

The crop growing in rainfed regions and agricultural production could be boosted by conserving soil water using soil additives like hydrogel. Meanwhile these hydrogels could be helpful to make water available for sustainable agriculture under rainfed regions (Johnson and Leah, 1990). The conservation of rainwater using additives could improve the crop status under rainfed regions as in our studies and it can be instrumental to ensure local food security. Our findings were at par with Zhang et al., 2007 who emphasized on the use of hydrogel to conserve soil water with integration of modern techniques to improve crop yield in rainfed areas. The positive effect of hydrogels to improve crop performance under dry conditions was reported by Keshavars et al., (2012). They concluded that application of super absorbent polymer resulted to increased WUE and highest conversion of dry matter to grain due to good translocation potential of crop because of availability of water even under water stress.

4.3.3Wheat Agronomic Parameters

4.3.3.1Wheat grain yield

The effect of soil additives used for summer crops on grain yield of subsequently grown wheat in winter was significant, along with the years and the interactions of soil additives and the years (Appendix 30). Use of soil additives improved grain yield of wheat and among the soil additives, highest grain yield was recorded for hydrogel (2684.7 kg/ha), and it was followed by compost, while FYM and gypsum were at par with each other. The lowest grain yield was recorded in control plots (2120 kg/ha), that was 27 % less than hydrogel treated plots. Higher wheat grain yield (2595 kg/ha) was observed during the second year i.e. 2011-12. The increase in grain yield during the second year (2011-12) than first year was 16 %. On the other hand, cropping systems did not significantly affect wheat grain yield (Table 4.3.22).

The interactive effect of Y x SA was significant and rest of the interactions were non- significant. Maximum wheat grain yield (2796.5 kg/ha) was observed in plots where hydrogel was used and compost was at par with it during the second year. The effect of FYM and gypsum on wheat grain yield was comparable with each other during both years. The incorporation of hydrogel in soil showed 52% increase in wheat grain yield over the control which exhibited minimum grain yield (1828 kg/ha) during 2010-11 (Table 4.3.23).

Crop yield could be improved under water limited environments by capturing every drop of rainfall to meet the goal of more crop per drop. This could be achieved by adopting specific crop and soil management practices such as soil additives (Kijne et al., 2003). The soil additives hydrogel, FYM, compost and gypsum helped to increase water retention in the soil resultingin increased crop yields (Table 2). Albaladejo*et al*., (2012) reported an increase in soil water holding capacity by soil additives such as hydrogel. Moreover, incorporation of soil additives in soil improves soil structure and makes soil as C sink rather than C source. However, under traditional cultivation methods, most of carbon is lost due to intensive tillage but by application of additives, organic carbon in soil increases significantly resulting to maximum availability of water (Ludwig et al., 2010). Effective use of available physical resources helps to have enhanced crop productivity under different cropping system (ACIAR, 2010).

Table 4.3.22 Yield and Yield attributes of wheat as influenced by different soil additives and cropping systems during both years

Years	Number of Tillers	Grains/Spike	Spikelet Per Spike	1000 Grain Weight	Biological Yield	Grain Yield	Harvest Index
2010-11	149.37B	37.533B	12.95B	41.55B	5942.1B	2237.1B	37.9A
2011-12	175.20A	44.167A	15.167A	48.667A	6973.4A	2595.8A	37.383B
LSD for Y	18.509	4.503	1.5178	4.8366	771.25	273.74	0.1434
Cropping Systems							
CS1	165.13B	41.633B	14.367A	45.967B	6551.7B	2408.4	37.1C
CS2	167.57A	42.133A	14.533A	46.533A	6682.9A	2419.1	36.4D
CS3	159.27C	40.067C	13.80B	44.20C	6328.1C	2414.8	38.3B
CS4	157.17D	39.567D	13.533C	43.733D	6268.3C	2423.6	38.767A
LSD for CS	1.6559	0.3945	0.1828	0.4348	110.57	NS	0.3407
Soil Additives							
Control	132.17D	33.375D	11.417D	36.792D	5266.4D	2120.8D	40.292A
Hydrogel	188.75A	47.583A	16.333A	52.542A	7502.2A	2684.7A	35.833C
FYM	155.79C	39.125C	13.458C	43.292C	6186.7C	2359C	38.125B
Compost	177.33B	44.583B	15.458B	49.292B	7037.1B	2517.2B	35.833C
Gypsum	157.38C	39.583C	13.625C	43.625C	6296.3C	2400.6C	38.125B
LSD for SA	3.7604	0.9377	0.3931	1.044	168.9	61.821	0.2658
Interaction							
Y x CS	NS	NS	NS	NS	NS	NS	NS
Y x SA	***	***	***	***	***	***	NS
CS x SA	*	*	NS	**	NS	NS	***
Y x CS x SA	NS	NS	NS	NS	NS	NS	NS

The physical resources include proper selection of crop and soil managements. The CS efficiency could be increased by the use of soil amendments or adopting suitable cropping system having additional crop in it (Wivstad et al., 2008). Chen *et al*. (2010) depicted that increasing availability of soil water through various techniques could increase choice of crop selection for the rainfed farmers. The moisture contents present within the soil profile is the basic necessity for healthy plant establishment. Soil additives applied for summer season crops improved the water retention of the soil even after the crop, as indicated by water content of the soil (Table Soil Moisture). Hydrogel enhanced water holding capacity of the soil to a greater degree as compared to the other soil additives which ultimately increased grain yield of subsequent wheat crop Akhter *et al*. (2004) also reported that hydrogel boosted water holding capacity of the soil. During 2011-12 higher grain yield recorded was due to timely occurrence of rains which helped to achieve better crop stand and growth than 2010-11 as indicated by number of tillers, grains per spike and spikelet per spike.

4.3.3.2 Biological yield

The effect of soil additives used for summer crops on biological yield of subsequently grown wheat in winter was significant, along with the years and the interactions of soil additives and the years (Appendix 31). The effect of soil additives used for summer crops on subsequent biological yield of wheat was significant. Highest biological yield was recorded for hydrogel (7502 kg/ha) and it was higher than compost (7037 kg/ha), while FYM (6186 kg/ha) and gypsum (6296 kg/ha) were at par with each other (Table 4.3.22). The lowest biological yield was recorded in control plots (5266 kg/ha), that was 42 % less than hydrogel treated plots. All the cropping system differed significantly for wheat biological yield. Highest biological yield was recorded under CS2 (6682 kg/ha) and it was higher than CS1 (6551.7 kg/ha) while lowest biological yield (6268 kg/ha) were observed under CS4 followed by CS3 (6328.1 kg/ha). Mungbean-Wheat cropping system recorded 6 % higher biological yield over CS4. Maximum wheat biological yield (6973 kg/ha) was observed during second year i.e. 2011-12, while minimum biological yield (5942 kg/ha) was recorded during first year i.e. 2010-11. The increase in biological yield during second year (2011-12) than first year was 17 %.

The interactive effect of SA x Y biological yield was highly significant and rest of the interactions were non- significant (Table 4.3.22). Maximum wheat biological yield (7858 kg/ha) was observed during 2011-12 in plots where hydrogel was applied whereas minimum biological yield (4500 kg/ha) recorded under control during 2010-11 and this increase was 74 % (Table 4.3.24).

The main effects of years, cropping system (CS) and soil additives (SA) on wheat biological yield differed significantly. Meanwhile, the interactive effect of Y x SA on biological yield remained highly significant while all other interactions remained non-significant. Maximum biological yield recorded during second year (6961 kg/ha) while minimum biological yield recorded during 2010-11 (5932 kg/ha). There was 14 % difference among both the years for wheat biological yield. Among CS the Highest biological yield (6652 kg/ha) observed under CS2 (Mungbean-Wheat) while lowest (6244 kg/ha) biological yield recorded under CS4 (Mungbean/Sorghum-Wheat). The Mungbean-Wheat cropping system depicted 6 % more biological yield than Fallow-Wheat cropping system. Similar trend for biological yield was observed for all the soil additives. Wheat biological yield was higher (7502 kg/ha) under hydrogel application than other soil additives while, lowest biological yield was recorded under control treatment (5250 kg/ha). Under hydrogel 42 % more biological yield was recorded than control treatment.

The Y x SA interactive effect remained significant at 1% P level (Table 4.1.3) and it revealed that highest biological yield recorded under hydrogel soil additive during 2011-12 (7858 kg/ha) compared to other soil additives whereas, lowest biological yield recorded under control treatment during 2010-11 (4529 kg/ha). There was 42 % increment in biological yield during 2011-12 under hydrogel application compared to control treatment during 2010-11.

The highest biological yield of Rabi crop (wheat) after legume might be due to fact that legume can fix atmosphere nitrogen effectively which will ultimately improves soil nutrient status resulting to good growth of crops. Meanwhile, earlier researcher in their findings reported that wheat yield increases significantly due to sowing of legume crops in the cropping pattern (Gan et al. 2003). They further concluded that increase yield might be due to residual nitrogen and soil water prior to sowing of crop due to previous legume crop. Similarly, Norwood (2000) concluded in their findings that winter yield remained highest when planted after legume crops compared to fallowing. Robertson et al., (2010) in their findings concluded that rotations with legume crops could be an option for enhanced crop biomass and productivity with good economic returns. The synergistic effect of following crops was earlier reported by Anderson (2005) who concluded that yield of wheat crop increased due to synergistic effect of crops on crop establishment parameters like

Table 4.3.23Interactive effect of Y x SA on Wheat Grain Yield

Soil Additives	2009-10	2011-12	Mean
Control	1828.1f	2413.5c	2120.8D
Hydrogel	2572.9b	2796.5a	2684.7A
FYM	2202e	2516.0b	2359C
Compost	2327.2cd	2707.2a	2517.2B
Gypsum	2255.5de	2545.8b	2400.6C
Mean	2237.1B	2595.8A	
LSD for Y x SA	93.223		

Table 4.3.24 Interactive effect of Y x SA on Wheat Biological Yield

Soil Additives	2009-10	2011-12	Mean
Control	4500.5f	6032.3d	5266.4D
Hydrogel	7146.2b	7858.3a	7502.2A
FYM	5729.5e	6643.8c	6186.7C
Compost	6463.8c	7610.4a	7037.1B
Gypsum	5870.7de	6721.9c	6296.3C
Mean	5942.1B	6973.4A	
LSD for Y x SA			

germination percentage which resulted to highest yield similar to our findings. Meanwhile increased wheat yield due to break crop system compared to continuous wheat cropping system was reported by Kirkegaard*et al*. (2008) who concluded highest wheat yield under break crop system. The increased germination percentage in our finding similar to Kirkegaard*et al*. (2008) might be due to residual fertility (N and P), and greater available soil water at planting following the break crop than following a previous wheat crop. The effect of previous crops on water availability for next crops resulted to highest germination percentage as reported by Hatfield *et al*. (2001). They further elaborated that crop residues due to previous crops might resulted to differences in soil water contents at planting of crops like wheat which might result to highest germination percentage. The findings of Unger and Vigil, (1998) and Gregory *et al*., (2005) concluded that suitable cropping patterns could maintain soil water by increased organic matter content, improved soil structure and water holding capacity. Soil additives also increased moisture contents of the soil. Similar to our finding Rana et al., 2006 concluded that soil additives could efficiently enhance water holding capacity of the soil which ultimately enhanced grain and biological yield of crops.

4.3.3.3 Harvest index

The effect of soil additives used for summer crops on harvest index of subsequently grown wheat in winter was significant, along with the years, cropping system and the interactions of soil additives and the years (Appendix 32). All the treatments (soil additive) differed significantly for harvest index. Highest harvest index was recorded for control treatment (40.29 %) while, FYM and gypsum were at par with each other. The lowest harvest index was recorded in hydrogel treated plots

(35.83 %), that was 12 % less than control plots (Table 4.3.22). All the cropping system differed significantly for wheat harvest index. Highest harvest index was recorded under CS4 (38.77 %) and it was higher than CS3 (38.3) while lowest harvest index (36.4) was observed under CS2. Sorghum/Mungbean-Wheat intercrop cropping pattern recorded 6 % higher harvest index compared to CS2. Both the years varied considerably for harvest index of wheat crop. Maximum harvest index (37.7) was observed during first year i.e. 2010-10, while minimum harvest index (37.3) was recorded during second year (2011-12). The increase in harvest index during 2010-11 than 2011-12 year was 1 %.

The interactive effect of CS x SA was highly significant and rest of the interactions were non- significant (Table 4.2.22). Highest wheat harvest index (41.5 %) was observed under Mungbean/Sorghum-Wheat cropping system under control treatment whereas, and it was higher than CS1 lowest harvest index (128.17) was recorded under Mungbean-Wheat cropping system (Table 4.3.25). Hydrogel treatment under Mungbean-wheat cropping system got 52 % higher wheat harvest index than control treatment under Mungbean-Sorghum intercrop-wheat cropping system.

4.3.3.4 Number of tillers

The effect of soil additives used for summer crops on number of tillers of subsequently grown wheat in winter was significant, along with the years, cropping system and the interactions of soil additives and the years (Appendix 33). The effect of soil additives used for summer crops on number of tillers of subsequent wheat was significant (Table 4.2.22). Highest number of tillers was recorded for hydrogel (188.75) and it was higher than compost (177.33), while FYM (155.79) and gypsum

(157.38) were at par with each other. The lowest number of tillers was recorded in control plots (132.17) that were 42 % less than hydrogel treated plots. All the cropping system differed significantly for number of tillers. Highest number of tillers was recorded under CS2 (167.57) and it was higher than CS1 (165.13) while lowest number of tillers (157.17) were observed under CS4. Mungbean-Wheat cropping system recorded 6 % higher number of tillers over CS4. Both the years varied considerably for number of tillers of wheat crop. Maximum number of tillers (175.2) was observed during second year i.e. 2011-12, while minimum number of tillers (149.3) was recorded during first year i.e. 2010-11. The increase in number of tillers during second year (2011-12) than first year was 17 %.

The interactive effects of Y x SA and CS x SA were highly significant and rest of the interactions were non- significant (Table 4.3.22. Maximum wheat number of tillers (197.75) was observed during 2011-12 in plots where hydrogel was used whereas minimum number of tillers (114) recorded under control during 2010-11 (Table 4.3.26). For interactive effect (Y x SA) during 2011-12 for hydrogel treatment there was 42 % increase in number of tillers over control treatment during 2010-11. Likewise, highest wheat number of tillers (195.67) was observed under Mungbean-wheat cropping system where hydrogel was used whereas, lowest wheat number of tillers (128.17) was recorded under Mungbean-Sorghum intercrop-Wheat cropping system (Table 4.3.27). Hydrogel treatment under Mungbean-wheat cropping system got 52 % higher wheat number of tillers than control treatment under Mungbean-Sorghum intercrop-wheat cropping system.

The significant increase in number of tillers in CS2 compared to other cropping system in present study was due to additive effect of adjoining crop. The use of additive crop like Mungbean resulted to conservation of soil water and nutrients. Since water storage in the soil is serious issue of world and its increasing day by day due to extensive agriculture. It’s necessary to use such type of system which can sustain the available natural resources on long time span. The earlier researcher in their findings concluded that water use efficiency could be improved by modifying existing cropping system compared to traditional one (Connor, 2004; Ma et al., 2008). More crop per drop the famous slogan by Kijne et al., (2003) could only be achieved by conserving soil water under rainfed agriculture which is possible by modification in the cropping system and use of hydrogels. Similarly, by adopting such techniques might resulted to reduction in the water loss due to transpiration as earlier it was reported that up to 40% of the total available soil water was found to be lost by soil evaporation in wheat in Australia (Siddique et al., 1990). Therefore, by the use of hydrogels same like present studies and change in the cropping system might resulted to reduced soil evaporation by fast vigorous seedling growth and high water use efficiency as concluded by Rebetzke and Richards, (1999).

Drought stress is main concerned for rainfed agriculture and it reduces crop yield potential significantly as concluded by Martinez, (2007). Wheat is main crop cultivated largely in different parts of world (Emam et al, 2007) and its yield is under severe threat due to deficiency in soil water. Since grain yield of wheat is outcome of interactive effect of yield components like number of tillers, spikelets per spike, grains per spike and thousand grain weight (Dencic, 2000) therefore, management of yield

Table 4.3.25 Interactive effect of CS x SA on Wheat Harvest Index

Soil Additives	**CS1**	**CS2**	**CS3**	**CS4**	**Mean**
Control	40.17b	39.33c	40.17b	41.5a	40.29A
Hydrogel	35.17h	34.33i	36g	37.83de	35.83C
FYM	37.5Erf	37f	39.67bc	38.33d	38.13B
Compost	35.17h	34.33i	36g	37.83de	35.83C
Gypsum	37.5ef	37f	39.67bc	38.33d	38.13B
Mean	37.1C	36.4D	38.3B	38.77A	

LSD for CS x SA 0.5532

Table 4.3.26 Interactive effect of Y x SA on Wheat Number of tillers

Soil Additives	2009-10	2011-12	Mean
Control	114.08h	150.25f	132.17D
Hydrogel	179.75c	197.75a	188.75A
FYM	144.25g	167.33de	155.79C
Compost	163.17e	191.5b	177.33B
Gypsum	145.58fg	169.17d	157.38C
Mean	149.37B	175.20A	

LSD for SA x Y 5.7732

Table 4.3.27Interactive effect of CS x SA on Wheat number of tillers

Soil Additives	CS1	CS2	CS3	CS4	Mean
Control	130.83j	139i	130.67j	128.17j	132.17D
Hydrogel	194a	195.67a	185.83b	179.5bc	188.75A
FYM	156.67fgh	161.5ef	153.83fgh	151.17h	155.79C
Compost	183.67b	184.17b	173.17cd	168.33de	177.33B
Gypsum	160.5efg	157.5fgh	152.83gh	158.67fgh	157.38C
Mean	165.13B	167.57A	159.27C	157.17D	

LSD for CS x SA 8.1645

components is an important task. Drought stress have significant negative effect on the number of tillers but this effect could be minimized by the use of soil additives which can conserve soil water and make that water available to the crops at the time of need. Use of hydrogel in present study resulted to increased number of tillers which was due to high water retention in soil and reduction in the leaching losses. The use of hydrogel also resulted to increased crop yield due to escape of crop from water stress. Similar results were reported by Widiatuti,(2008) and Green, (2004) who concluded that hydrogels have potential to increase crop yield under arid conditions of world. The hydrogels have potential to absorbs water four hundred times greater than the weight they have as reported by Monnig, (2005). Meanwhile, Nazarli et al, (2010) were of the view that hydrogels reduces the irrigation number to 50% by retaining maximum water in the soil. The increased availability of water in the soil similar to our findings was also reported by Wu et al, (2008) who stated that hydrogels could retained 10% more water in the soil compared to control treatments.

4.3.3.5 Grains per spike

The effect of soil additives used for summer crops on number of grains per spike of subsequently grown wheat in winter was significant, along with the years, cropping system and the interactions of soil additives and the years (Appendix 34). The effect of soil additives used for summer crops on number of grains per spike of subsequent wheat was significant (Table 4.3.22). Highest number of grains per spike was recorded for hydrogel (47.58) and it was higher than compost (44.58), while FYM (39.12) and gypsum (39.58) were at par with each other. The lowest number of grains per spike was recorded in control plots (33.37) that were 42 % less than hydrogel treated plots. All the cropping system differed significantly for number of grains per spike. Maximum number of grains per spike was calculated under CS2 (42.13) and it was higher than CS1 (41.63) while minimum number of grains per spike (39.56) were observed under CS4 which were higher than CS3 (40.06). Mungbean-Wheat cropping system recorded 6 % higher number of grains per spike over CS4. Both the years varied potentially for number of grains per spike of wheat crop. Maximum number of grains per spike (48.67) was observed during 2011-12, while minimum number of grains per spike (41.55) was recorded during 2010-11. The increase in number of grains per spike during second year than first year was 17 %.

The interactive effects of Y x SA and CS x SA were highly significant for number of grains per spike and rest of the interactions were non- significant (Table 4.3.22). Maximum wheat number of grains per spike (54.91) was observed during 2011-12 in plots where hydrogel was used whereas minimum number of grains per spike (31.75) recorded under control during 2010-11 (Table 4.3.28). For interactive effect (Y x SA) during 2011-12 for hydrogel treatment there was 73 % increase in number of grains per spike over control treatment during 2010-11. Likewise, highest wheat number of grains per spike (49.33) was observed under Mungbean-wheat cropping system where hydrogel was used whereas, lowest wheat number of grains per spike (32.5) was recorded under Mungbean-Sorghum intercrop-Wheat cropping system (Table 4.3.29). Hydrogel treatment under Mungbean-wheat cropping system got 51 % higher wheat number of grains per spike than control treatment under Mungbean-Sorghum intercrop-wheat cropping system.

The increased number of grains per spike in present study due to Mungbean-wheat cropping system was due to efficient use of available resources (ACIAR, 2010). The efficiency of the system could also be improved by diagnosing the defects in the existing cropping system and replacing that defects with new systems to utilize resources effectively (Dore et al., 2008 and Wivstad et al., 2008). The Mungbean-Wheat system could be an alternative to Fallow-Wheat cropping system under rainfed conditions. The results of our findings were also depicted by earlier researcher who concluded that availability of irrigation could increase choice of selection of crops for the rainfed farmers (Chen et al., 2010). Similarly, inclusion of legume crop like mungbean in the system might result to increased N contents of soil which might increases yield of coming wheat crop compared to other cropping patterns. Similar results were reported by earlier researcher about increased yield and N due to grain legumes system compared to monoculture where cereal was planted only (Kirkegaard et al. 2008). The 49% increased wheat crop yield in Australia due to inclusion of legumes in cropping patterns reported by Evans et al. (2003) which might be due to increased N in soil. However, Peoples and Craswell (1992) concluded 37% increased wheat crop yield due to use of legume in cropping patterns. Meanwhile, Angus et al., 2001 in their findings concluded that yield might increases to 40-50% due to inclusion of grain legumes in the cropping patterns even if N application is limited. However, Stevenson and van Kessel (1996) reported 91 % increased wheat yield when pea was used as legume crops in cropping system. The reduced grains per meter square after sorghum might due to its excessive utilization of nutrients which resulted to poor soil structure and availability of soil water. The negative impacts of exhaustive crops like

Table 4.3.28Interactive effect of Y x SA on Wheat grains per spike

Soil Additives	2009-10	2011-12	Mean
Control	28.75h	38f	33.375D
Hydrogel	45.25c	49.917a	47.583A
FYM	36.167g	42.083de	39.125C
Compost	40.917e	48.25b	44.583B
Gypsum	36.583fg	42.583d	39.583C
Mean	37.533B	44.167A	
LSD for SA x Y	1.4281		

Table 4.3.29 Interactive effect of CS x SA on Wheat grains per spike

Soil Additives	CS1	CS2	CS3	CS4	Mean
Control	33.167u	35.00i	32.833j	32.50j	33.375D
Hydrogel	48.833ab	49.333a	47.00bc	45.167cd	47.583A
FYM	39.333gh	40.50fg	38.667gh	38.00h	39.125C
Compost	46.333c	46.167c	43.50de	42.333ef	44.583B
Gypsum	40.50fg	39.667gh	38.333h	39.833gh	39.583C
Mean	41.633B	42.133A	40.067C	39.567D	
LSD for CS x SA	2.0196				

sorghum and maize was reported by earlier researcher who concluded that crops planted before wheat have impacts on water in arid environments as recharge might not occur due to these crops in summer and which might affect the growth of wheat or other crops like Gram and Canola significantly (Norwood, 2000). Therefore, they suggested removing fallow-wheat system and they suggested use of such crops which are not exhaustive in nature (Miller et al. 2002; Gan et al. 2003).

The WUE under rainfed agriculture could be improved by soil managements which includes use of soil additives like hydrogels. The hydrogels increases soil water availability to the crop resulted to high WUE. Sharma, (2004) in his findings concluded that hydrogels have potential to conserve soil water and crop establishment. The good establishment of crop further resulted to good vegetative and reproductive growth of crop and highest yield. Similar results were also reported by Allahdadi et al., (2005) and El-Hady et al., (2009). The work of Huang and Petrovic, (1994) confirmed the use of super absorbent polymers to conserve soil water. Meanwhile, Zhang et al., (2007) concluded that hydrogels have great potential to increase plant growth and production indirectly by storing soil water and reclamation of soil. Our results were similar to Johnson and Leah, (1990) who concluded that hydrogel are good source to store water and have potential to improve rainfed agriculture.

4.3.3.6 Spikelets per spike

The effect of soil additives used for summer crops on number of spikelets per spike of subsequently grown wheat in winter was significant, along with the years, cropping system and the interactions of soil additives and the years (Appendix 35). The effect of soil additives used for summer crops onnumber of spikelets per spike of subsequent wheat was significant (Table 4.3.22). Highest number of spikelets per spike was recorded for hydrogel (16.33) and it was higher than compost (15.45), while FYM (13.45) and gypsum (13.62) were at par with each other. The lowest number of spikelets per spike was recorded in control plots (11.41) that were 43 % less than hydrogel treated plots. All the cropping system varied significantly for number of spikelets per spike. Maximum number of spikelets per spike was calculated under CS2 (14.53) followed by CS1 (14.36) while minimum number of spikelets per spike (13.53) were observed under CS4 which were higher than CS3 (13.80). Mungbean-Wheat cropping system recorded 7 % higher number of spikelets per spike over CS4. Both the years varied significantly for number of spikelets per spike of wheat crop. Maximum number of spikelets per spike (15.17) was observed during 2011-12, while minimum number of spikelets per spike (12.95) was recorded during 2010-11. The increase in number of spikelets per spike during 2011-12 than 2010-11 was 17 %.

The interactive effect of Y x SA was highly significant for number of spikelets per spike and rest of the interactions were non- significant (Table 4.3.22). Maximum wheat number of spikelets per spike (17.25) was observed during 2011-12 in plots where hydrogel was used whereas minimum number of spikelets per spike (10) recorded under control during 2010-11 (Table 4.3.30). For interactive effect (Y x SA) during 2011-12 for hydrogel treatment there was 72 % increase in number of spikelets per spike over control treatment during 2010-11.

The increased spikelets per spike due to cropping system might be due to additive effect of legume crop which resulted to good crop growth and development. Similar results were reported by Struik and Bonciarelli, (1997) who concluded that cropping system with legume could maximize the beneficial processes like nitrogen fixation resulted to increased availability of nutrients. Meanwhile, sustainable cropping patterns resulted to improvement in the soil structure and good establishment of crop. Similarly, Van Ittersum and Rabbinge, (1997) were of the view that cropping system should be environmental friendly as it might results to overall recycling of all essential nutrients in the soil. The highest spikelet per spike in our studies was due to synergistic effect of legume crop on the system. Wu, (2008) and Ma et al., (2008) in their findings concluded that increased water use efficiency and yield could be achieved by transition in the cropping system from Fallow to legume base. The legume based cropping system resulted to higher recharge of water due to increased infiltration and drainage as concluded by O‘Connell et al., (2003). Similar conclusion was also made by Farahani et al., (1998) who depicted that legume in the cropping system resulted to higher water availability in the soil and good crop yield. Similar to our findings increased number of spikelets per spike was reported by Liu et al., (2009) due to sustainable cropping system like induction of legumes with main crops like wheat.

Water scarcity is main concerned of rainfed agriculture. However, this issue could be solved by using soil additives which can conserve soil water and increased crop yield. The increased spikelets per spike in present studies due to hydrogel was due to availability of soil water resulted to good crop growth, development and yield. The use of soil additives as soil conditioners was earlier reported by Shainberg et al., (1990) who concluded improved soil structure due to use of soil conditioners. Yangyuoru et al., (2006) reported increased water storage due to use of soil additives while El-Hady et al., (2009) concluded that soil additives increases water availability to the crops.

The use of hydrogel could improve water availability to the crops by increasing the retention pores and decreasing drainage pores even under sandy soils as concluded by El-Hady and Abo-Sedera, (2006). Similar results were observed by Leciejewski (2009) and Paluszek and Zembrowski (2008) who concluded that hydrogel could be good option to increase soil water status and crop productivity. Similarly, water retention capacity of soil could also be increased by hydrogel application (Abedi-Koupai and Sohrab, 2004).

4.3.3.7 Thousand grains weight (g)

The effect of soil additives used for summer crops on thousand grains weight (TGW) of subsequently grown wheat in winter was significant, along with the years, cropping system and the interactions of soil additives and the years (Appendix 36). The effect of soil additives used for summer crops on thousand grains weight of successive wheat was significant (Table 4.3.22). Highest thousand grains weight was recorded for hydrogel (52.54) and it was higher than compost (49.29), while FYM (43.29) and gypsum (43.62) were at par with each other. The lowest thousand grains weight was recorded in control plots (36.79) that were 42 % less than hydrogel treated plots. Similarly, all the cropping system varied significantly for thousand grains weight. Maximum thousand grains weight was calculated under Mungbean-Wheat cropping system (46.53 g) and it was higher than CS1 (45.96 g) while minimum thousand grains weight (45.96 g) were observed under CS4. Mungbean-Wheat cropping system recorded 6 % higher thousand grains weight (TGW)over CS4. In the

Same way both the years varied significantly for thousand grains weight of wheat crop. Maximum thousand grains weight (48.67 g) was observed during second year (2011-12), while minimum number of spikelets per spike (41.55 g) was recorded during first year (2010-11). The increase in thousand grains weight during 2011-12 than 2010-11 was 17 %.

The interactive effects of Y x SA and CS x SA were highly significant for thousand grains weight and rest of the interactions were non- significant (Table 4.3.22). Maximum wheat thousand grains weight (54.91 g) was observed during 2011-12 in plots where hydrogel was used whereas minimum thousand grains weight (31.75 g) recorded under control during 2010-11 (Table 4.3.31). For interactive effect Y x SA during 2011-12 for hydrogel treatment there was 72 % increase in thousand grains weight over control treatment during 2010-11. Similarly, highest thousand grains weight (54.50 g) was observed under Mungbean-wheat cropping system where hydrogel was used whereas, lowest wheat thousand grains weight (35.67 g) was recorded under Mungbean-Sorghum intercrop-Wheat cropping system. Hydrogel treatment under Mungbean-wheat cropping system got 53 % higher wheat thousand grains weight than control treatment under Mungbean-Sorghum intercrop-wheat cropping system (Table 4.3.32).

The cropping system affected TGW significantly but highest TGW was recorded for CS2 compared to control. The results were in line with earlier findings who concluded that intercropping with legumes crops increases TGW and crop yield by improving soil nutritional status. They also concluded that with intercropping farmers can have more crops on a unit piece of land resulting to highest resource use efficiency compared to sole cropping. Meanwhile, intercropping also resulted to nitrogen availability to companion crop and increased soil organic matter (Getachew et al., 2007). Furthermore, Wortmann et al., (2009) reported increased TGW and crop yield due to intercropping. However, our results were at par with Himayatullah (1991) who recorded decreased crop yield due to intercropping. The detrimental effect of intercropping on TGW in our studies might be due to completion for resources (light, water and nutrients) resulted to reduced TGW. Similar results were concluded by Malai and Muthasankaranarayanan, (1999) who sated that yield remained high under sole compared to intercropping.

Soil additives increased TGW compared to control and increase was high due to hydrogel soil additive and it remained 36 % higher than control. Viero et al. (2000) concluded that crop growth and yield could be improved by the application of hydrogels as soil amendments. Abedi-Koupai and Sohrab, (2004) was of the view that hydrogels have potentials to absorb maximum water and make that water available to plants to increase their growth and developments. The results were in line with Dehgan et al., (1994) who concluded that hydrogels is good option to grow plant under water limited conditions. They concluded that hydrogels enhances drought tolerance of crop under water stress resulted to highest thousand grain weight compared to control treatments.

Similarly, increase water content of soil was reported by Al-Sheik and Al-Darby (1996) due to application of hydrogels. They further elaborated that increased water status of soil helps in the establishment of crops effectively resulting to higher yield. Meanwhile, Specht and Harvey-Jones, (2000) reported that plant survival rate

Table 4.3.30 Interactive effect of Y x SA on Wheat Spikelet Per Spike

Soil Additives	2009-10	2011-12	Mean
Control	10.00f	12.833e	11.417D
Hydrogel	15.417c	17.25a	16.333A
FYM	12.50e	14.417d	13.458C
Compost	14.25d	16.667b	15.458B
Gypsum	12.583e	14.667d	13.625C
Mean	12.95B	15.167A	

LSD for SA x Y 0.5708

Table 4.3.31 Interactive effect of Y x SA on Wheat Thousand Grain Weight

Treatments	2009-10	2011-12	Mean
Control	31.75h	41.833f	36.792D
Hydrogel	50.167c	54.917a	52.542A
FYM	40.167g	46.417de	43.292C
Compost	45.333e	53.25b	49.292B
Gypsum	40.333fg	46.917d	43.625C
Mean	41.55B	48.667A	

LSD for SA x Y 1.5745

Table 4.3.32 Interactive effect of CS x SA on Wheat Thousand Grain Weight

Soil Additives	CS1	CS2	CS3	CS4	Mean
Control	36.50u	38.667i	36.333j	35.667j	36.792D
Hydrogel	54.00a	54.50a	51.667b	50.00bc	52.542A
FYM	43.667fgh	44.833ef	42.667fgh	42.00h	43.292C
Compost	51.167b	51.167b	48.00cd	46.833de	49.292B
Gypsum	44.5fg	43.50fgh	42.333gh	44.167fgh	43.625C
Mean	45.967B	46.533A	44.20C	43.733D	
LSD for CS x SA	2.2267				

was high due to hydrogels as they can retain water more in soil compared to control treatments.

4.4 GROWTH PARAMETERS

4.4.1 Mungbean Crop Growth Rate (g/m^2/day)

The effect of soil additives used for summer crops on crop growth rate of mungbean at 30 DAS among all the cropping system during both the years was significant (Appendix 37). Use of soil additives improved CGR of mungbean (Table 4.4.1). Among the soil additives, highest CGR was recorded for hydrogel (2.56), while control and gypsum were at par with each other. The lowest CGR was recorded in the plots where compost was applied (2.08) and it was lower than FYM (2.24). Change in crop growth rate was observed among sole and intercrop cropping system. Maximum mungbean CGR (2.53) was observed under sole mungbean cropping system while minimum CGR (2.08) was observed under intercrop cropping system. Bothe the years differed potentially for CGR at 30 DAS for mungbean. The higher mungbean crop growth rate (2.51) was observed during the 2010 whereas, lower crop growth rate (2.11) was observed during 2011. The interactive effect among Y x CS and Y x SA were significant while other interaction were non-significant. Three way interactive effect i.e. Y x CS x SA has been presented in table 4.4.2.

The effect of soil additives used for summer crops on crop growth rate of mungbean at 60 DAS among all the cropping system during both the years was significant (Appendix 38). Use of soil additives improved CGR of mungbean (Table 4.4.1). Among the soil additives, highest CGR was recorded for hydrogel (12.49), while control and gypsum were at par with each other. The lowest CGR was recorded

Table 4.4.1 Mungbean Crop Growth Rate as influenced by different soil additives and cropping systems during both years

Year	30 DAS	60 DAS	90 DAS
2010	2.5067A	12.229A	3.5663A
2011	2.1067B	10.314B	3.0083B
LSD	0.1695	1.0061	0.2954
Cropping Systems			
Sole	2.534A	12.361A	3.6043A
Intercrop	2.0793B	10.183B	2.9703B
LSD	0.0958	0.5286	0.1542
Soil Additives			
Control	2.3192B	11.422B	3.3308B
Hydrogel	2.5608A	12.491A	3.6425A
FYM	2.2375C	10.913C	3.1817C
Compost	2.075D	10.117D	2.9508D
Gypsum	2.3408B	11.417B	3.3308B
LSD	0.0774	0.3667	0.1066
Interactions			
Y*CS	**	**	**
Y*SA	NS	NS	NS
CS*SA	***	***	***
Y*CS*SA	NS	NS	NS

Table 4.4.2 Interactive effect on mungbean Crop Growth rate at 30 DAS as influenced by different soil additives and cropping systems during both years

Soil Additives	2010			2011		
	Sole	Intercrop	Mean	Sole	Intercrop	Mean
Control	2.9133	2.1167	2.515B	2.7167	1.53	2.1233EF
Hydrogel	2.4967	2.1167	2.7333A	2.1533	2.6233	2.3883CD
FYM	2.7367	2.1167	2.4467BC	2.4433	1.6133	2.0283F
Compost	2.4233	2.1167	2.325D	2.0967	1.5533	1.825G
Gypsum	2.7733	2.1167	2.5133B	2.5867	1.75	2.1683E
Mean	2.6687A	2.3447B		2.3993B	1.814C	

LSD for Y x CS	0.0754
LSD for Y x SA	0.1192
LSD for Y x CS x SA	NS

Table 4.4.3 Interactive effect on mungbean Crop Growth rate at 60DASas influenced by different soil additives and cropping systems during both years

Soil Additives	2010			2011		
	Sole	Intercrop	Mean	Sole	Intercrop	Mean
Control	14.23	10.32	12.275B	13.26	7.877	10.568E
Hydrogel	12.18	14.497	13.338A	10.5	12.787	11.643CD
FYM	13.353	10.52	11.937BC	11.917	7.863	9.89F
Compost	11.807	10.86	11.333D	10.22	7.58	8.9G
Gypsum	13.533	10.993	12.263B	12.61	8.53	10.57E
Mean	13.021A	11.438B		11.701B	8.927C	

LSD for Y x CS	0.3799
LSD for Y x SA	0.6007
LSD for Y x CS x SA	NS

in the plots where compost was applied (10.11) and it was lower than FYM (10.91). Change in crop growth rate was observed among sole and intercrop cropping system. Maximum mungbean CGR (12.36) was observed under sole mungbean cropping system while minimum CGR (10.18) was observed under intercrop cropping system. Bothe the years differed potentially for CGR at 60 DAS for mungbean. The higher mungbean crop growth rate (12.23) was observed during the 2010 whereas, lower crop growth rate (10.31) was observed during 2011. The interactive effect among Y x CS and Y x SA were significant while other interaction were non-significant. Three way interactive effect i.e. Y x CS x SA has been presented in table 4.4.3.

The effect of soil additives used for summer crops on crop growth rate of mungbean at 90 DAS among all the cropping system during both the years was significant (Appendix 39). Use of soil additives changed CGR of mungbean (Table 4.4.1). Among the soil additives, highest CGR was recorded for hydrogel (4.64), while control and gypsum were at par with each other. The lowest CGR was recorded in the plots where compost was applied (2.95) and it was lower than FYM (3.18). Change in crop growth rate was observed among sole and intercrop cropping system. Maximum mungbean CGR (3.60) was observed under sole mungbean cropping system while minimum CGR (2.97) was observed under intercrop cropping system. Bothe the years differed potentially for CGR at 90 DAS for mungbean. The higher mungbean crop growth rate (3.57) was observed during the 2010 whereas, lower crop growth rate (3.01) was observed during 2011. The interactive effect among Y x CS and Y x SA were significant while other interaction were non-significant. Three way interactive effect i.e. Y x CS x SA has been presented in table 4.4.4.

Table 4.4.4Interactive effect on mungbean Crop Growth rate at 90DASas influenced by different soil additives and cropping systems during both years

Soil Additives	2010			2011		
	Sole	Intercrop	Mean	Sole	Intercrop	Mean
Control	4.15	3.01	3.58B	3.8633	2.3	3.0817D
Hydrogel	3.55	4.23	3.89A	3.06	3.73	3.395C
FYM	3.8933	3.0667	3.48BC	3.4733	2.2933	2.8833E
Compost	3.4433	3.1667	3.305C	2.9833	2.21	2.5967F
Gypsum	3.9467	3.2067	3.5767B	3.68	2.49	3.085D
Mean	3.7967A	3.336B		3.412B	2.6047C	

LSD for Y x CS 0.1107

LSD for Y x SA 0.175

LSD for Y x CS x SA NS

4.4.2 Sorghum Crop Growth Rate(g/m^2/day)

The effect of soil additives used for summer crops on crop growth rate of sorghum at 30 DAS among all the cropping system during both the years was significant (Appendix 40). Use of soil additives improved CGR of sorghum (Table 4.4.5). Among the soil additives, highest CGR was recorded for hydrogel (4.385), while control and gypsum were at par with each other. The lowest CGR was recorded in the plots where compost was applied (3.5508) and it was lower than FYM (3.83). Change in crop growth rate was observed among sole and intercrop cropping system. Maximum sorghum CGR (4.3383) was observed under sole sorghum cropping system while minimum CGR (3.5607) was observed under intercrop cropping system. Bothe the years differed potentially for CGR at 30 DAS. The higher sorghum crop growth rate (4.2933) was observed during the 2010 whereas, lower crop growth rate (3.6057) was observed during 2011. The interactive effect among Y x CS and Y x SA were significant while other interaction were non-significant. Three way interactive effect i.e. Y x CS x SA has been presented in table 4.4..

The effect of soil additives used for summer crops on crop growth rate of sorghum at 60 DAS among all the cropping system during both the years was significant (Appendix 41). Use of soil additives improved CGR of sorghum (Table 4.4.5). Among the soil additives, highest CGR was recorded for hydrogel (21.686), while control and gypsum were at par with each other. The lowest CGR was recorded in the plots where compost was applied (17.56) and it was lower than FYM (18.95). Change in crop growth rate was observed among sole and intercrop cropping system.

Table 4.4.5 Sorghum Crop Growth Rate as influenced by different soil additives and cropping systems during both years

Year	30 DAS	60 DAS	90 DAS
2010	4.2933A	21.231A	5.945A
2011	3.6057B	17.907B	5.0133B
LSD	0.2926	1.7478	0.4921
Cropping system			
Sole	4.3383A	21.46A	6.008A
Intercrop	3.5607B	17.679B	4.9503B
LSD	0.1636	0.9219	0.2594
Soil Additives			
Control	3.9725B	19.828B	5.5517B
Hydrogel	4.385A	21.686A	6.0725A
FYM	3.8317C	18.947C	5.3042C
Compost	3.5508D	17.563D	4.9175D
Gypsum	4.0075B	19.822B	5.55B
LSD	0.1327	0.637	0.1794
Interactions			
Y*CS	**	**	**
Y*SA	NS	NS	NS
CS*SA	***	***	***
Y*CS*SA	NS	NS	NS

Table 4.4.6 Interactive effect on sorghum Crop Growth rate at 30DASas influenced by different soil additives and cropping systems during both years

Soil Additives	2010			2011		
	Sole	Intercrop	Mean	Sole	Intercrop	Mean
Control	5.0933	4.4867	4.3083B	3.86	3.5867	3.6367EF
Hydrogel	4.6533	4.14	4.6833A	3.6233	2.62	4.0867CD
FYM	4.7533	4.2733	4.1917BC	3.6933	2.76	3.4717F
Compost	4.69	4.1833	3.9767D	3.6867	2.6633	3.125G
Gypsum	4.9933	4.4233	4.3067B	3.8133	2.9933	3.7083E
Mean	4.57A	4.0167B		4.1067B	3.1047C	

LSD for Y x CS 0.1293

LSD for Y x SA 0.2044

LSD for Y x CS x SA NS

Table 4.4.7 Interactive effect on sorghum Crop Growth rate at 60DASas influenced by different soil additives and cropping systems during both years

Soil Additives	2010			2011		
	Sole	Intercrop	Mean	Sole	Intercrop	Mean
Control	24.703	17.917	21.31B	23.023	13.67	18.347E
Hydrogel	21.143	25.173	23.158A	18.227	22.2	20.213CD
FYM	23.183	18.26	20.722BC	20.69	13.653	17.172F
Compost	20.493	18.857	19.675D	17.743	13.16	15.452G
Gypsum	23.497	19.087	21.292B	21.893	14.813	18.353E
Mean	22.604A	19.859B		20.315B	15.499C	

LSD for Y x CS 0.6606

LSD for Y x SA 1.0444

LSD for Y x CS x SA NS

Maximum sorghum CGR (21.46) was observed under sole sorghum cropping system while minimum CGR (17.67) was observed under intercrop cropping system. Bothe the years differed potentially for CGR at 60 DAS. The higher sorghum crop growth rate (21.23) was observed during the 2010 whereas, lower crop growth rate (17.90) was observed during 2011. The interactive effect among Y x CS and Y x SA were significant while other interaction were non-significant. Three way interactive effect i.e. Y x CS x SA has been presented in table 4.4.7.

The effect of soil additives used for summer crops on crop growth rate of sorghum at 90 DAS among all the cropping system during both the years wassignificant (Appendix 42). Use of soil additives improved CGR of sorghum (Table 4.4.5). Among the soil additives, highest CGR was recorded for hydrogel (6.07), while control and gypsum were at par with each other. The lowest CGR was recorded in the plots where compost was applied (4.92) and it was lower than FYM (5.30).

Change in crop growth rate was observed among sole and intercrop cropping system. Maximum sorghum CGR (6.01) was observed under sole sorghum cropping system while minimum CGR (4.95) was observed under intercrop cropping system. Bothe the years differed potentially for CGR at 90 DAS. The higher sorghum crop growth rate (5.95) was observed during the 2010 whereas, lower crop growth rate (5.01) was observed during 2011.

The interactive effect among Y x CS and Y x SA were significant while other interaction were non-significant. Three way interactive effect i.e. Y x CS x SA has been presented in table 4.4.8.

Table 4.4.8Interactive effect on sorghum Crop Growth rate at 90DASas influenced by different soil additives and cropping systems during both years

Soil Additives	2010			2011		
	Sole	Intercrop	Mean	Sole	Intercrop	Mean
Control	6.9167	5.0167	5.9667B	6.4467	3.8267	5.1367D
Hydrogel	5.92	7.05	6.485A	5.1033	6.2167	5.66C
FYM	6.4867	5.1167	5.8017BC	5.79	3.8233	4.8067E
Compost	5.74	5.28	5.51C	4.9667	3.6833	4.325F
Gypsum	6.58	5.3433	5.9617B	6.13	4.1467	5.1383D
Mean	6.3287A	5.5613B		5.6873B	4.3393C	

LSD for Y x CS 0.186

LSD for Y x SA 0.294

LSD for Y x CS x SA NS

4.4.3 Wheat Crop Growth Parameters

4.4.3.1 Wheat crop growth rate(g/m^2/day)

There was a significant variation among two years, cropping systems and soil additives for wheat crop growth rate at Tillering stage (Appendix 43). The main effect of soil additives on wheat crop growth rate was highly significant. Highest wheat crop growth rate at tillering was recorded for gypsum (0.2608) while lowest wheat crop growth rate was recorded for compost treatment (0.2367) (Table 4.4.9). Gypsum soil additive recorded 10 % increase in wheat crop growth rate over compost. Similarly, all the cropping systems differed potentially for wheat crop growth rate at tillering stage. Maximum crop growth rate was observed for Mungbean-Wheat (0.2673) whereas minimum crop growth rate (0.219) was recorded under Fallow-Wheat cropping system. Under Mungbean-Wheat cropping system 22 % increase in wheat crop growth rate was recorded compared with Fallow-Wheat cropping system. Similarly, both the years varied potentially for wheat crop growth rate at tillering stage. Maximum wheat crop growth rate (0.2662) was observed during second year i.e. 2011-12, while minimum wheat crop growth rate (0.2267) was recorded during first year i.e. 2010-11. The increase in wheat crop growth rate during second year than first year was 17 %.

The interactive effect CS x SA was differed significantly for wheat crop growth rate while interactive effect like Y x SA, Y x CS and Y x CS x SA were non-significant. For interactive effect CS x SA highest wheat crop growth rate (0.2967) was observed under Fallow-Wheat cropping system from the plots where compost was added, as well as under Mungbean-Wheat cropping system where no soil additives were added whereas, lowest wheat crop growth rate (0.195) was recorded for Fallow-

Wheat cropping system under control treatment (Table 4.4.10). Compost treatment under Mungbean-Wheat cropping system got 52 % higher wheat crop growth rate than control treatment under Fallow-Wheat cropping system.

There was a significant variation among two years, cropping systems and soil additives for wheat crop growth rate at flag leaf stage (Appendix 44). The main effect of soil additives on wheat crop growth rate was highly significant. Highest wheat crop growth rate at flag leaf stage was recorded for gypsum (2.8013) while lowest wheat crop growth rate was recorded for compost treatment (2.5454) (Table 4.4.9). Gypsum soil additive recorded 10 % higher wheat crop growth rate over compost. Similarly, all the cropping systems differed significantly for wheat crop growth rate at flag leaf stage. Maximum crop growth rate was observed for Mungbean-Wheat (2.8683) whereas minimum crop growth rate (2.362) was recorded under Fallow-Wheat cropping system. Under Mungbean-Wheat cropping system 21 % greater wheat crop growth rate was recorded compared with Fallow-Wheat cropping system. Similarly, both the years varied significantly for wheat crop growth rate at flag leaf stage. Maximum wheat crop growth rate (2.8627) was observed during second year i.e. 2011-12, while minimum wheat crop growth rate (2.439) was recorded during first year i.e. 2010-11. The increase in wheat crop growth rate during second year than first year was 16 %.

The interactive effect CS x SA was varied significantly for wheat crop growth rate while interactive effect like Y x SA, Y x CS and Y x CS x SA were non-significant at flag leaf stage. For interactive effect CS x SA highest wheat crop growth rate (3.19) was observed under Mungbean-Wheat cropping system where no soil additives were added whereas, lowest wheat crop growth rate (2.1083) was recorded for Fallow-Wheat cropping system under control treatment (Table 4.4.11). Control treatment under Mungbean-Wheat cropping system got 50 % higher wheat crop growth rate than control treatment under Fallow-Wheat cropping system.

There was a significant variation among two years, cropping systems and soil additives for wheat crop growth rate at anthesis stage (Appendix 45). The main effect of soil additives on wheat crop growth rate was highly significant. Highest wheat crop growth rate (16.768) at anthesis stage was recorded for gypsum while lowest (15.235) wheat crop growth rate was recorded for compost treatment (Table 4.4.9). Gypsum soil additive recorded 11 % increase in wheat crop growth rate over compost. Similarly, all the cropping systems differed considerably for wheat crop growth rate at anthesis stage. Maximum crop growth rate was observed for Mungbean-Wheat (17.167) whereas minimum crop growth rate (14.143) was recorded under Fallow-Wheat cropping system. Under Mungbean-Wheat cropping system 20 % greater wheat crop growth rate was recorded compared to Fallow-Wheat cropping system. Similarly, both the years varied significantly for wheat crop growth rate at anthesis stage. Maximum wheat crop growth rate (17.136) was recorded during 2011-12, while minimum wheat crop growth rate (14.602) was recorded during 2010-11. The increase in wheat crop growth rate during second year than first year was 17 %.

The interactive effect CS x SA was varied pointedly for wheat crop growth rate while interactive effects like Y x SA, Y x CS and Y x CS x SA were non-significant at anthesis stage. For interactive effect CS x SA maximum wheat crop growth rate

Table 4.4.9Wheat Crop Growth Rate as influenced by different soil additives and cropping systems during both years

Years	Z-20	Z-47	Z-60	Z-85
2010-11	0.2267B	2.439B	14.602B	2.9707B
2011-12	0.2662A	2.8627A	17.136A	3.4867A
LSD for Y	0.0296	0.3173	1.8964	0.3851
Cropping Systems				
CS1	0.219D	2.362D	14.143D	2.878D
CS2	0.2673A	2.8683A	17.167A	3.4923A
CS3	0.256B	2.757B	16.505B	3.3587B
CS4	0.2433C	2.616C	15.661C	3.1857C
LSD for CS	0.0108	0.1108	0.6551	0.133
Soil Additives				
Control	0.245BC	2.6371BC	15.79BC	3.2121BC
Hydrogel	0.2421C	2.5946CD	15.535CD	3.1608CD
FYM	0.2475B	2.6758B	16.017B	3.2588B
Compost	0.2367D	2.5454D	15.235D	3.100D
Gypsum	0.2608A	2.8013A	16.768A	3.4117A
LSD for SA	0.005304	0.0536	0.3198	0.0654
Interaction				
Y x CS	NS	NS	NS	NS
Y x SA	NS	NS	NS	NS
CS x SA	***	***	***	***
Y x CS x SA	NS	NS	NS	NS

Table 4.4.10 Interactive effect of CS x SA on Wheat CGR at tillering

Soil Additives	CS1	CS2	CS3	CS4	Mean
Control	0.195i	0.296a	0.2317fg	0.2567de	0.245BC
Hydrogel	0.2117h	0.2833ab	0.23g	0.2433efg	0.2421C
FYM	0.1967i	0.2733bc	0.2767b	0.2433efg	0.2475B
Compost	0.1967i	0.2383fg	0.28b	0.2317fg	0.2367D
Gypsum	0.296a	0.245ef	0.2617cd	0.2417fg	0.2608A
Mean	0.219D	0.2673A	0.256B	0.2433C	
LSD for CS x SA	0.0147				

Table 4.4.11 Interactive effect of CS x SA on Wheat CG Rate Flag leaf stage

Soil Additives	CS1	CS2	CS3	CS4	Mean
Control	2.1083j	3.19a	2.5083gh	2.7417ef	2.6371BC
Hydrogel	2.2633i	3.0333bc	2.465h	2.6167fg	2.5946CD
FYM	2.1333ij	2.9317cd	2.9983c	2.64fg	2.6758B
Compost	2.14ij	2.555gh	2.9917c	2.495gh	2.5454D
Gypsum	3.165ab	2.6317fg	2.8217de	2.5867gh	2.8013A
Mean	2.362D	2.8683A	2.757B	2.616C	

LSD for CS x SA 0.1509

Table 4.4.12 Interactive effect of CS x SA on Wheat CG Rate at Anthesis

Soil Additives	CS1	CS2	CS3	CS4	Mean
Control	12.635j	19.092a	15.013gh	16.422ef	15.79BC
Hydrogel	13.562i	18.157bc	14.757h	15.665fg	15.535CD
FYM	12.763ij	17.547cd	17.953c	15.805fg	16.017B
Compost	12.807ij	15.297gh	17.91c	14.928gh	15.235D
Gypsum	18.948ab	15.745fg	16.89de	15.487gh	16.768A
Mean	14.143D	17.167A	16.505B	15.661C	
LSD for CS x SA	0.898				

(19.092) was observed under Mungbean-Wheat cropping system where no soiladditives were added whereas, lowest wheat crop growth rate (12.635) was recorded for Fallow-Wheat cropping system under control treatment (Table 4.4.12). Control treatment under Mungbean-Wheat cropping system got 34 % higher wheat crop growth rate than control treatment under Fallow-Wheat cropping system at anthesis stage.

There was a significant variation among two years, cropping systems and soil additives for wheat crop growth rate at dough stage (Appendix 46). The main effect of soil additives on wheat crop growth rate was highly significant. Highest wheat crop growth rate at dough was recorded for gypsum (3.4117) while lowest wheat crop growth rate (3.1) was recorded for compost treatment (Table 4.4.9). Gypsum soil additive recorded 10 % increase in wheat crop growth rate over compost. Similarly, all the cropping systems varied potentially for wheat crop growth rate at dough stage. Maximum crop growth rate was observed for Mungbean-Wheat (3.4923) whereas minimum crop growth rate (2.878) was recorded under Fallow-Wheat cropping system. Under Mungbean-Wheat cropping system 21 % increase in wheat crop growth rate at dough stage was recorded compared with Fallow-Wheat cropping system. Similarly, both the years varied potentially for wheat crop growth rate at dough stage. Maximum wheat crop growth rate (3.4867) was observed during second year i.e. 2011-12, while minimum wheat crop growth rate (2.9707) was recorded during first year i.e. 2010-11. The increase in wheat crop growth rate during second year than first year was 16 %.

The interactive effect CS x SA was differed considerably for wheat crop

4.4.13 Interactive effect of CS x SA on Wheat CGR at Dough stage

Soil Additives	CS1	CS2	CS3	CS4	Mean
Control	2.57j	3.8833a	3.055gh	3.34ef	3.2121BC
Hydrogel	2.76i	3.6933bc	3.0033h	3.1867fg	3.1608CD
FYM	2.5967ij	3.57cd	3.6533c	3.215fg	3.2588B
Compost	2.6067ij	3.1117gh	3.645c	3.0367gh	3.100D
Gypsum	3.8567ab	3.2033gfg	3.4367de	3.15gh	3.4117A
Mean	2.878D	3.4923A	3.3587B	3.1857C	

LSD for CS x SA 0.1829

growth rate at dough stage while interactive effects like Y x SA, Y x CS and Y x CS xSA were non-significant. For interactive effect CS x SA highest wheat crop growth rate (3.8833) was observed under Mungbean-Wheat cropping system where no soil additives were added whereas, lowest wheat crop growth rate (2.57) was recorded for Fallow-Wheat cropping system under control treatment (Table 4.4.13). Control treatment under Mungbean-Wheat cropping system got 31% higher wheat crop growth rate than control treatment under Fallow-Wheat cropping system.

4.4.3.2 Wheat leaf area index

There was a significant variation among two years, cropping systems and soil additives for wheat leaf area index at Z-47 i.e. flag leaf stage (Appendix 47). The main effect of soil additives on wheat leaf area index was highly significant. Highest wheat leaf area index at flag leaf stage was recorded for hydrogel treatment (5.7246) while lowest wheat leaf area index was recorded for compost treatment (5.2008) (Table 4.4.14). Hydrogel soil additive recorded 9 % higher wheat leaf area index over compost. Similarly, all the cropping systems differed significantly for wheat leaf area index at flag leaf stage. Maximum leaf area index was observed for Mungbean-Wheat (5.8613) whereas minimum leaf area index (4.8283) was recorded under Fallow-Wheat cropping system. Under Mungbean-Wheat cropping system 21 % greater wheat leaf area index was recorded compared with Fallow-Wheat cropping system. Similarly, both the years varied significantly for wheat leaf area index at flag leaf stage. Maximum wheat leaf area index (5.8503) was observed during second year i.e. 2011-12, while minimum wheat leaf area index (4.9855) was recorded during first year i.e. 2010-11. The increase in wheat leaf area index during second year than first year was 14 %.

The interactive effect CS x SA was varied significantly for wheat leaf area index while interactive effect like Y x SA, Y x CS and Y x CS x SA were non-significant at flag leaf stage. For interactive effect CS x SA highest wheat leaf area index (6.5167) was observed under Mungbean-Wheat cropping system where no soil additives were added whereas, lowest wheat leaf area index (4.3133) was recorded for Fallow-Wheat cropping system under control treatment (Table 4.4.15). Control treatment under Mungbean-Wheat cropping system got 33 % higher wheat leaf area index than control treatment under Fallow-Wheat cropping system.

4.4.3.3 Wheat leaf area duration

There was a significant variation among two years, cropping systems and soil additives for wheat leaf area duration at Z-47 i.e.flag leaf stage (Appendix 48). The main effect of soil additives on wheat leaf area duration was highly significant. Highest wheat leaf area duration (83.845) at flag leaf stage was recorded for hydrogel treatment while lowest (76.175) wheat leaf area duration was recorded for compost treatment (Table 4.4.14). Hydrogel soil additive recorded 9 % increase in wheat leaf area duration over compost. Similarly, all the cropping systems differed considerably for wheat leaf area duration at flag leaf stage. Maximum leaf area duration was observed for Mungbean-Wheat (85.835) whereas minimum leaf area duration (70.717) was recorded under Fallow-Wheat cropping system. Under Mungbean-Wheat cropping system 21 % greater wheat leaf area duration was recorded compared to Fallow-Wheat cropping system. Similarly, both the years varied considerably for wheat leaf area

Table 4.4.14 Wheat Growth Parameters as influenced by different soil additives and cropping systems during both years

Year	Leaf Area Index	Leaf Area duration	Net Assimilation Rate
2010-11	4.9855B	73.011B	2.6532B
2011-12	5.8503A	85.681A	3.1138A
LSD	0.6466	9.4771	0.3435
Cropping Systems			
CS1	4.8283D	70.717D	2.569D
CS2	5.8613A	85.835A	3.1193A
CS3	5.635B	82.523B	2.9993B
CS4	5.347C	78.308C	2.8463C
LSD	0.2237	3.2752	0.119
Soil Additives			
Control	5.3908BC	78.946BC	2.8688BC
Hydrogel	5.7246A	83.845A	3.0475A
FYM	5.4683B	80.09B	2.9096B
Compost	5.2008D	76.175D	2.7692D
Gypsum	5.305CD	77.675CD	2.8225CD
LSD	0.1089	1.599	0.0584
Interaction			
Y*CS	NS	NS	NS
Y*SA	NS	NS	NS
CS*SA	***	***	***
Y*CS*SA	NS	NS	NS

Table 4.4.15 Interactive effect of CS x SA on Wheat LAI at Flag Leaf Stage

Soil Additives	CS1	CS2	CS3	CS4	Mean
Control	4.3133j	6.5167a	5.1267gh	5.6067ef	5.3908BC
Hydrogel	6.4683ab	5.3767fg	5.7667de	5.2867gh	5.7246A
FYM	4.3583ij	5.9917cd	6.1283c	5.395fg	5.4683B
Compost	4.3717ij	5.2217gh	6.1133c	5.0967gh	5.2008D
Gypsum	4.63i	6.2bc	5.04h	5.35fg	5.305CD
Mean	4.8283D	5.8613A	5.635B	5.347C	

LSD for CS x SA 0.3062

Table 4.4.16Interactive effect of CS x SA on Wheat LAI at Flag Leaf Stage

Soil Additives	CS1	CS2	CS3	CS4	Mean
Control	63.18j	95.447a	75.058gh	82.098ef	78.946BC
Hydrogel	94.75ab	78.74fg	84.453de	77.435gh	83.845A
FYM	63.832ij	87.74cd	89.763c	79.023fg	80.09B
Compost	64.027ij	76.473gh	89.55c	74.648gh	76.175D
Gypsum	67.798i	90.777bc	73.792h	78.335fg	77.675CD
Mean	70.717D	85.835A	82.523B	78.308C	

LSD for CS x SA 4.4893

Table 4.4.17Interactive effect of CS x SA on Wheat NAR at Flag Leaf Stage

Soil Additives	CS1	CS2	CS3	CS4	Mean
Control	2.295j	3.4683a	2.7283gh	2.9833ef	2.8688BC
Hydrogel	3.4433ab	2.8617fg	3.07de	2.815gh	3.0475A
FYM	2.3183ij	3.1883cd	3.2617c	2.87fg	2.9096B
Compost	2.3267ij	2.78gh	3.255c	2.715gh	2.7692D
Gypsum	2.4617i	3.2983bc	2.6817h	2.8483fg	2.8225CD
Mean	2.569D	3.1193A	2.9993B	2.8463C	

LSD for CS x SA 0.1634

duration at flag leaf stage. Maximum wheat leaf area duration (85.681) was recorded during 2011-12, while minimum wheat leaf area duration (73.011) was recorded during 2010-11. The increase in wheat leaf area duration during second year than first year was 14 %. The interactive effect CS x SA was varied pointedly for wheat leaf area duration while interactive effects like Y x SA, Y x CS and Y x CS x SA were non-significant at flag leaf stage. For interactive effect CS x SA maximum wheat leaf area duration (95.447) was observed under Mungbean-Wheat cropping system where no soil additives were added whereas, lowest wheat leaf area duration (63.18) was recorded for Fallow-Wheat cropping system under control treatment (Table 4.4.16). Control treatment under Mungbean-Wheat cropping system got 33 % higher wheat leaf area duration than control treatment under Fallow-Wheat cropping system at flag leaf stage.

4.4.3.4 Wheat net assimilation rate

There was a significant variation among two years, cropping systems and soil additives for wheat net assimilation rate at Z-47 i.e. flag leaf stage (Appendix 49). The main effect of soil additives on wheat net assimilation rate was highly significant. Highest wheat net assimilation rate at flag leaf was recorded for hydrogel (3.0475) while lowest wheat net assimilation rate (2.7692) was recorded for compost treatment (Table 4.4.14). Hydrogel soil additive recorded 10 % increase in wheat net assimilation rate over compost. Similarly, all the cropping systems varied potentially for wheat net assimilation rate at flag leaf stage. Maximum net assimilation rate was observed for Mungbean-Wheat (3.1193) whereas minimum net assimilation rate (2.569) was recorded under Fallow-Wheat cropping system. Under Mungbean-Wheat cropping system 20 % increase in wheat net assimilation rate at flag leaf stage was recorded compared with Fallow-Wheat cropping system. Similarly, both the years varied potentially for wheat net assimilation rate at flag leaf stage. Maximum wheat net assimilation rate (3.1138) was observed during second year i.e. 2011-12, while minimum wheat net assimilation rate (2.6532) was recorded during first year i.e. 2010-11. The increase in wheat net assimilation rate during second year than first year was 14 %.

The interactive effect CS x SA was differed considerably for wheat net assimilation rate at flag leaf stage while interactive effects like Y x SA, Y x CS and Y x CS x SA were non-significant. For interactive effect CS x SA highest wheat net assimilation rate (3.4683) was observed under Mungbean-Wheat cropping system where no soil additives were added whereas, lowest wheat net assimilation rate (2.295) was recorded for Fallow-Wheat cropping system under control treatment (Table 4.4.17). Control treatment under Mungbean-Wheat cropping system got 34% higher wheat net assimilation rate than control treatment under Fallow-Wheat cropping system.

4.4.4 Sorghum Physiological Attributes

4.4.4.1 Sorghum photosynthetic rate (μ mole/m2/s)

There was a significant difference between the two years, soil additives and their interaction (CS x SA) for sorghum photosynthetic rate (Appendix 50). The effect of soil additives used before summer crops on photosynthetic rate of sorghum was significant. Highest photosynthetic rate was recorded for hydrogel (28.003 μ mole/m^2/s) while lowest photosynthetic rate recorded for control treatment (24.66 μ mole/m^2/s). Hydrogel additive recorded 11 % higher sorghum photosynthetic rate over control. On the other hand, the cropping systems did not vary considerably for photosynthetic rate. Maximum photosynthetic rate (27.875 µ mole/m^2/s) was observed during first year i.e. 2010, while minimum photosynthetic rate (25.34 µ mole/m^2/s) was recorded during second year i.e. 2011. The increase in photosynthetic rate during first year (2010) than first year was 9%. On the other hand, cropping systems main effect did not significantly effect sorghum photosynthetic rate (Table 4.4.18).

The interactive effect of CS x SA was varied significantly and rest of the interactions were non- significant (Table 4.4.17). Maximum wheat photosynthetic rate (28.27 µ mole/m^2/s) was observed under Sorghum/Mungbean-Wheat intercrop cropping system from the plots where hydrogel was used whereas minimum photosynthetic rate (24.87 µ mole/m^2/s) recorded for control treatment under Sorghum-Wheat cropping system and this increase was 12 % (Table 4.4.19).

4.4.4.2 Sorghum transpiration rate (mole/m2/s)

The analysis of variance table revealed that main effect of soil additives, cropping systems and years was significant for transpiration rate (E) of wheat crop (Appendix 51). All the treatments (soil additive) differed significantly for transpiration rate. Highest transpiration rate was recorded for hydrogel (8.1586) while lowest harvest index recorded for control and compost treatments (7.35 mole/m^2/s). Control treatment recorded 1 % higher transpiration rate over hydrogel soil additive (Table 4.4.18). All the cropping system differed significantly for sorghum transpiration rate.

Table 4.4.18 Sorghum Physiological Attributes as influenced by different soil additives and cropping systems during both years

Years	Photosynthetic Rate	Transpiration Rate	Stomatal Conductance
2010	25.346B	7.6267B	0.66B
2011	27.875A	7.7431A	0.781A
LSD	2.2102	0.046	0.0479
Cropping System			
Sorghum-Wheat	26.552	7.7225A	0.7246A
Intercrop-Wheat	26.669	7.6473B	0.7163B
LSD	NS	0.0136	0.00196
Soil Additives			
Control	25.033C	7.3498C	0.5967E
Hydrogel	28.003A	8.1586A	0.8304A
FYM	26.534B	7.7832B	0.692D
Compost	26.416B	7.3498C	0.7748B
Gypsum	27.067B	7.7832B	0.7085C
LSD	0.9341	0.051	0.0122
Interaction			
Y*CS	NS	NS	NS
Y*SA	NS	NS	NS
CS*SA	***	***	***
Y*CS*SA	NS	NS	NS

Table 4.4.19Interactive effect of CS x SA on Sorghum Photosynthetic rate

Soil Additives	Sorghum-Wheat	Intercrop-Wheat	Mean
Control	24.875e	25.192cde	25.033C
Hydrogel	28.213a	27.792ab	28.003A
FYM	25.115de	27.953a	26.534B
Compost	26.507bc	26.325cd	26.416B
Gypsum	28.052a	26.082cde	27.067B
Mean	26.552	26.669	

Table 4.4.20Interactive effect of CS x SA on Sorghum Transpiration Rate

Soil Additives	Sorghum-Wheat	Intercrop-Wheat	Mean
Control	8.0384b	8.2787a	8.1586A
Hydrogel	7.1633f	7.5362e	7.3498C
FYM	7.9357c	7.6307d	7.7832B
Compost	7.1633f	7.5362e	7.3498C
Gypsum	7.9357c	7.6307d	7.7832B
Mean	7.7225A	7.6473B	

Table 4.4.21Interactive effect of Y x SA on Sorghum Stomatal Conductance

Soil Additives	2010	2011	Mean
Control	0.4989h	0.6945f	0.5967E
Hydrogel	0.7922c	0.8685a	0.8304A
FYM	0.6414g	0.7426e	0.692D
Compost	0.7127f	0.837b	0.7748B
Gypsum	0.6547g	0.7624d	0.7085C
Mean	0.66B	0.781A	

Table 4.4.22Interactive effect of CS x SA on Sorghum Stomatal Conductance

Soil Additives	Sorghum-Wheat	Intercrop-Wheat	Mean
Control	0.595g	0.5983g	0.5967E
Hydrogel	0.8453a	0.8154b	0.8304A
FYM	0.6994f	0.6845f	0.692D
Compost	0.7873c	0.7624d	0.7748B
Gypsum	0.6961f	0.721e	0.7085C
Mean	0.7246A	0.7163B	

Higher transpiration rate was recorded under Sorghum-Wheat cropping system (7.72 mole/m^2/s) while lower transpiration rate (7.64 mole/m^2/s) were observed under Sorghum/Mungbean-Wheat cropping system. Both the years varied significantly for transpiration rate of sorghum. Maximum transpiration rate (7.74 mole/m^2/s) was observed during second year i.e. 2011, while minimum transpiration rate (7.64 mole/m^2/s) was recorded during first year (2010). The increase in transpiration rate during 2010 than 2011 was 1 %.

The interactive effect of CS x SA was highly significant and rest of the interactions were non- significant (Table 4.4.18). Highest sorghum transpiration rate (8.28 mole/m^2/s) was observed under Mungbean/Sorghum-Wheat cropping system under control treatment whereas, lowest transpiration rate (7.16 mole/m^2/s) was recorded under Sorghum-Wheat cropping system with hydrogel treatment (Table 4.4.20). Control treatment under Sorghum/Mungbean-wheat intercrop cropping system got 2 % higher transpiration rate than hydrogel treatment under Sorghum-Wheat cropping system.

4.4.4.3 Sorghum stomatal conductance gs (mole m^{-2} s^{-1})

There was a significant difference between the two years, cropping systems, soil additives and their interactions (Y x SA, Y x CS and CS x SA) for wheat stomatal conductance (Appendix 52). The effect of soil additives used before summer plantation on stomatal conductance of sorghum was significant (Table 4.4.18). Highest stomatal conductance was recorded for hydrogel (0.83 mole m^{-2} s^{-1}) while lowest stomatal conductance recorded for control treatment (0.59 mole m^{-2} s^{-1}). Hydrogel additive recorded 28 % increase in stomatal conductance over control for sorghum crop. Similarly, all the cropping systems differed noticeably for stomatal conductance. Highest stomatal conductance (0.72 mole m^{-2} s^{-1}) was recorded under Sorghum-Wheat cropping system while lowest stomatal conductance (0.71) was recorded under Sorghum/Mungbean-Wheat intercrop cropping system. Stomatal conductance for both the years was also significantly different. Maximum stomatal conductance (0.78 mole m^{-2} s^{-1}) was observed during second year i.e. 2011, while minimum stomatal conductance (0.68 mole m^{-2} s^{-1}) was recorded during first year i.e. 2010. The increase in stomatal conductance during second year (2011) than first year was 17%.

The interactive effect of Y x SA and CS x SA were varied significantly and other were non- significant. Maximum sorghum stomatal conductance (0.87 mole m^{-2} s^{-1}) was observed during 2011 from the plots where hydrogel was used (Table 4.4.21) whereas minimum stomatal conductance (0.4989) recorded for control treatment during 2010 and this increase was 49 % . Similarly, for interactive effect CS x SA the highest sorghum stomatal conductance (0.85 mole m^{-2} s^{-1}) was observed under Sorghum-Wheat cropping system under hydrogel treatment whereas, lowest stomatal conductance (0.59 mole m^{-2} s^{-1}) was recorded under Sorghum-Wheat cropping system with control treatment (Table 4.4.22).

4.4.5 Mungbean Physiological Attributes

4.4.5.1 Mungbean photosynthetic rate

There was a significant difference between the two years, soil additives and their interaction (CS x SA) for mungbean photosynthetic rate (Appendix 53). The effect of soil additives used before summer crops on photosynthetic rate of mungbean was significant (Table 4.4.23). Highest photosynthetic rate was recorded for hydrogel

(30.95 μ mole/m^2/s) while lowest photosynthetic rate recorded for compost (24.95 μ mole/m^2/s). Hydrogel additive recorded 19 % higher mungbean photosynthetic rate over control. On the other hand, the cropping systems differed considerably for photosynthetic rate. Maximum photosynthetic rate (31.69 μ mole/m^2/s) was observed under Mungbean/Sorghum-Wheat intercrop cropping system, while minimum photosynthetic rate (25.89 μ mole/m^2/s) was recorded under Mungbean-Wheat cropping system. Similarly, maximum photosynthetic rate (30.10 μ mole/m^2/s) was observed during first year i.e. 2010, while minimum photosynthetic rate (27.49 μ mole/m^2/s) was recorded during second year i.e. 2011. The increase in photosynthetic rate during first year (2010) than second year was 9%. The interactive effect of CS x SA was varied significantly and rest of the interactions were non- significant. Maximum mungbean photosynthetic rate (36.24 μ mole/m^2/s) was observed under Sorghum/Mungbean-Wheat intercrop cropping system from the control plots followed by hydrogel treatment (36.03 μ mole/m^2/s) whereas minimum photosynthetic rate (22.89 μ mole/m^2/s) recorded for control treatment under Mungbean-Wheat cropping system and this increase was 36 % (Table 4.4.24).

4.4.5.2 Mungbean transpiration rate

The analysis of variance table revealed that main effect of soil additives, cropping systems and years was significant for transpiration rate (E) of mungbean crop (Appendix 54). All the treatments (soil additive) differed significantly for transpiration rate (Table 4.4.23). Highest transpiration rate was recorded for hydrogel (7.89 mole/m^2/s) while lowest transpiration rate recorded for control treatment (6.91 mole/m^2/s) and compost treatments (6.91 mole/m^2/s). Control treatment recorded 2 %

higher transpiration rate over hydrogel soil additive. All the cropping system differed significantly for mungbean transpiration rate. Higher transpiration rate was recorded under Mungbean-Wheat cropping system (7.37 mole/m^2/s) while lower transpiration rate (7.25 mole/m^2/s) were observed under Sorghum/Mungbean-Wheat cropping system. Both the years varied significantly for transpiration rate of mungbean. Maximum transpiration rate (7.35 mole/m^2/s) was observed during first year i.e. 2010, while minimum transpiration rate (7.26 mole/m^2/s) was recorded during second year (2011). The increase in transpiration rate during 2010 than 2011 year was 1 %.

The interactive effect of CS x SA was highly significant and rest of the interactions were non- significant. Highest mungbean transpiration rate (7.99 mole/m^2/s) was observed under Mungbean-Wheat cropping system under control treatment whereas, lowest transpiration rate (6.84 mole/m^2/s) was recorded under Mungbean/Sorghum-Wheat intercrop cropping system with hydrogel treatment (Table 4.4.25). Control treatment under Mungbean-wheat cropping system got 2 % higher transpiration rate than hydrogel treatment under Mungbean/Sorghum-Wheat intercrop cropping system.

4.4.5.3 Mungbean stomatal conductance (gs)

There was a significant difference between the two years, cropping systems, soil additives and their interactions (Y x SA, Y x CS and CS x SA) for mungbean stomatal conductance (Appendix 55). The effect of soil additives used before summer plantation on stomatal conductance of mungbean was significant (4.4.23). Highest stomatal conductance was recorded for hydrogel (0.88 mole m^{-2} s^{-1}) while

Table 4.4.23 Mungbean Physiological Attributes as influenced by different soil additives and cropping systems during both years

Years	Photosynthetic Rate	Transpiration Rate	Stomatal Conductance
2010	27.495B	7.3533A	0.8148A
2011	30.102A	7.2628B	0.6997B
LSD	2.3736	0.0358	0.0455
Cropping System			
Mungbean-Wheat	31.698A	7.3712A	0.7647A
Intercrop-Wheat	25.898B	7.2449B	0.7498B
LSD	1.5356	0.0228	0.0032
Soil Additives			
Control	29.563AB	6.9106C	0.6091D
Hydrogel	30.955A	7.8934A	0.8867A
FYM	29.772AB	7.4127B	0.7226C
Compost	24.954C	6.9106C	0.8345B
Gypsum	28.748B	7.4127B	0.7334C
LSD	1.8354	0.0548	0.0145
Interaction			
Y*CS	NS	NS	NS
Y*SA	NS	NS	NS
CS*SA	***	***	***
Y*CS*SA	NS	NS	NS

Table 4.4.24Interactive effect of CS x SA on Mungbean Photosynthetic rate

Soil Additives	Mungbean-Wheat	Intercrop-Wheat	Mean
Control	22.888D	36.237A	29.563AB
Hydrogel	25.883C	36.027A	30.955A
FYM	25.733C	33.81A	29.772AB
Compost	24.15CD	25.758C	24.954C
Gypsum	30.837B	26.66C	28.748B
Mean	25.898B	31.698A	

Table 4.4.25Interactive effect of CS x SA on Mungbean Transpiration Rate

Soil Additives	Mungbean-Wheat	Intercrop-Wheat	Mean
Control	7.997a	7.7898b	7.8934A
Hydrogel	6.9744e	6.8467f	6.9106C
FYM	7.455c	7.3705d	7.4127B
Compost	6.9744e	6.8467f	6.9106C
Gypsum	7.455c	7.3705d	7.4127B
Mean	7.3712A	7.2449B	

Table 4.4.26Interactive effect of CS x SA on Mungbean Stomatal Conductance

Soil Additives	Mungbean-Wheat	Intercrop-Wheat	Mean
Control	0.5884f	0.6298e	0.6091D
Hydrogel	0.8834a	0.89a	0.8867A
FYM	0.711d	0.7342c	0.7226C
Compost	0.8353b	0.8337b	0.8345B
Gypsum	0.7309cd	0.7359c	0.7334C
Mean	0.7647A	0.7498B	

lowest stomatal conductance recorded for control treatment (0.61 mole m^{-2} s^{-1}). Hydrogel additive recorded 28 % increase in stomatal conductance over control for mungbean crop. Similarly, all the cropping systems differed noticeably for stomatal conductance. Highest stomatal conductance (0.77 mole m^{-2} s^{-1}) was recorded under Mungbean-Wheat cropping system while lowest stomatal conductance (0.75 mole m^{-2} s^{-1}) was recorded under Sorghum/Mungbean-Wheat intercrop cropping system. Stomatal conductance for both the years was also significantly different. Maximum stomatal conductance (0.81 mole m^{-2} s^{-1}) was observed during first year i.e. 2011, while minimum stomatal conductance (0.699 mole m^{-2} s^{-1}) was recorded during second year i.e. 2010. The increase in stomatal conductance during second year (2011) than first year was 17%. The interactive effect of CS x SA was highly significant and rest of the interactions were non- significant. Highest mungbean stomatal conductance (0.89 mole m^{-2} s^{-1}) was observed for Intercrop-Wheat cropping system under hydrogel treatment followed by Mungbean-Wheat cropping system under hydrogel treatment (0.88 mole m^{-2} s^{-1}) whereas, lowest stomatal conductance (0.58 mole m^{-2} s^{-1}) was recorded under Mungbean-Wheat intercrop cropping system with control treatment (Table 4.4.26). Hydrogel treatment under Mungbean/Sorghum-Wheat intercrop cropping system got 34 % higher stomatal conductance than control treatment under Mungbean-Wheat cropping system.

4.4.6Wheat Physiological Attributes

4.4.6.1 Wheat photosynthetic rate

There was a significant difference between the two years, cropping systems, soil additives and their interaction (CS x SA) for wheat photosynthetic rate (Appendix

56). The effect of soil additives used for summer crops on photosynthetic rate of wheat was significant (Table 4.4.27). Highest photosynthetic rate was recorded for hydrogel (34.22 μ mole/m^2/s) while lowest photosynthetic rate recorded for control treatment (24.66). Hydrogel additive recorded 38 % higher wheat photosynthetic rate over control. Similarly, all the cropping systems varied considerably for photosynthetic rate. Highest photosynthetic rate (28.99 μ mole/m^2/s) was recorded under Mungbean-Wheat cropping system while lowest photosynthetic rate (25.958 μ mole/m^2/s) was recorded under Fallow-Wheat cropping system. Maximum wheat photosynthetic rate (28.989 μ mole/m^2/s) was observed during second year i.e. 2011-12, while minimum photosynthetic rate (26.42) was recorded during first year i.e. 2010-11. The increase in photosynthetic rate during second year (2010-11) than first year was 9% .

The interactive effect of CS x SA was varied significantly and rest of the interactions were non- significant (Table 4.4.28). Maximum wheat photosynthetic rate (36.237 μ mole/m^2/s) was observed under Mungbean-Wheat cropping pattern from the plots where hydrogel was used whereas minimum photosynthetic rate (22.888 μ mole/m^2/s) recorded for control treatment under Fallow-Wheat cropping pattern and this increase was 58 %.

4.4.6.2 Wheat transpiration rate

The analysis of variance table revealed that main effect of soil additives, cropping systems and years was significant for transpiration rate (E) of wheat crop (Appendix 57). All the treatments (soil additive) differed significantly for

Table 4.4.27 Wheat Physiological Attributes as influenced by different soil additives and cropping systems during both years

Years	**Photosynthetic Rate**	**Transpiration rate**	**Stomatal conductance**
2010-11	26.42B	7.5903A	0.6837B
2011-12	28.99A	7.4863B	0.8023a
LSD for Y	2.2764	0.00448	0.0882
Cropping Systems			
CS1	25.958B	7.4123C	0.754B
CS2	28.989A	7.2853D	0.769A
CS3	28.822A	7.69B	0.728C
CS4	27.048B	7.7657A	0.720C
LSD for CS	1.5408	0.0574	0.0129
Soil Additives			
Control	24.664D	8.0708A	0.606D
Hydrogel	34.228A	7.170C	0.863A
FYM	25.95C	7.6404B	0.711C
Compost	26.926B	7.170C	0.809B
Gypsum	26.755BC	7.6404B	0.725C
LSD for SA	0.8127	0.0376	0.0129
Interaction			
Y x CS	NS	NS	NS
Y x SA	NS	NS	NS
CS x SA	*	*	*
Y x CS x SA	NS	NS	NS

transpiration rate (Table 4.4.27). Highest transpiration rate was recorded for control treatment (8.08 mole/m^2/s) while lowest transpiration rate was recorded for hydrogel treatment (7.17 mole/m^2/s). Control treatment recorded 2 % higher transpiration rate over hydrogel soil additive. All the cropping system differed significantly for wheat transpiration rate. Higher transpiration rate was recorded under CS4 (7.76 mole/m^2/s) while lower transpiration rate (7.28 mole/m^2/s) were observed under CS2. CS4 recorded 1 % higher transpiration rate compared to CS2. Both the years varied significantly for transpiration rate of wheat crop. Maximum transpiration rate (7.59 mole/m^2/s) was observed during first year i.e. 2010-11, while minimum transpiration rate (7.48 mole/m^2/s) was recorded during second year (2011-12). The increase in transpiration rate during 2010-11 than 2011-12 year was 1 %.

The interactive effect of CS x SA was highly significant and rest of the interactions were non- significant. Highest wheat transpiration rate (8.32 mole/m^2/s) was observed under Mungbean/Sorghum-Wheat cropping system under control treatment whereas, lowest transpiration rate (6.885 mole/m^2/s) was recorded under Mungbean-Wheat cropping system with hydrogel treatment. Hydrogel treatment under Mungbean-wheat cropping system got 28 % higher wheat transpiration rate than control treatment under Mungbean-Sorghum intercrop-wheat cropping system (Table 4.4.29.

4.4.6.3 Wheat stomatal conductance (gs)

There was a significant difference between the two years, cropping systems, soil additives and their interaction (CS x SA) for wheat stomatal conductance

Table 4.4.28Interactive effect of CS x SA on Wheat Photosynthetic rate

Soil Additives	CS1	CS2	CS3	CS4	Mean
Control	22.888i	25.883fgh	25.733gh	24.15hi	24.664D
Hydrogel	30.837c	36.237a	36.027a	33.81b	34.228A
FYM	25.758gh	26.66d-g	26.507d-g	24.875ghi	25.95C
Compost	25.115gh	28.213d	28.052de	26.325d-g	26.926B
Gypsum	25.192gh	27.953de	27.792def	26.082e-h	26.755BC
Mean	25.958B	28.989A	28.822A	27.048B	

Table 4.2.29 Interactive effect of Cropping systems (CS) x Soil additives (SA) on Wheat Transpiration Rate

Soil Additives	CS1	CS2	CS3	CS4	Mean
Control	8.042bc	7.8333d	8.0833b	8.325a	8.0708A
Hydrogel	7.0133i	6.885j	7.2033h	7.5783f	7.170C
FYM	7.4967f	7.4117g	7.98c	7.6733e	7.6404B
Compost	7.0133i	6.885j	7.2033h	7.5783f	7.170C
Gypsum	7.4967f	7.4117g	7.98c	7.6733e	7.6404B
Mean	7.4123C	7.2853D	7.69B	7.7657A	

Table 4.4.30 Interactive effect of Year (Y) x Soil Additives (SA)on Sorghum Wheat Conductance

Soil Additives	2010-11	2011-12	Mean
Control	0.5167g	0.6958e	0.606D
Hydrogel	0.8225b	0.9042a	0.863A
FYM	0.6592f	0.7633cd	0.711C
Compost	0.7433d	0.875a	0.809B
Gypsum	0.6767ef	0.7733c	0.725C
Mean	0.6837B	0.8023A	

(Appendix 58). The effect of soil additives used for summer crops on stomatal conductance of subsequent wheat was significant (Table 4.4.27). Highest stomatal conductance was recorded for hydrogel (0.8633 mole m^{-2} s^{-1}) while lowest stomatal conductance recorded for control treatment (0.61 mole m^{-2} s^{-1}). Hydrogel additive recorded 42 % increase in stomatal conductance over control for wheat crop. Similarly, all the cropping systems differed noticeably for stomatal conductance. Highest stomatal conductance (0.76 mole m^{-2} s^{-1}) was recorded under Mungbean-Wheat cropping system while lowest stomatal conductance (0.75 mole m^{-2} s^{-1}) was recorded under Fallow-Wheat cropping system. Stomatal conductance for both the years was also significantly different. Maximum stomatal conductance (0.80 mole m^{-2} s^{-1}) was observed during second year i.e. 2011-12, while minimum stomatal conductance (0.68 mole m^{-2} s^{-1}) was recorded during first year i.e. 2010-11. The increase in stomatal conductance during second year (2010-11) than first year was 17%. The interactive effect of Y x SA was varied significantly and other were non-significant. Maximum wheat stomatal conductance (0.87 mole m^{-2} s^{-1}) was observed during 2011-12 from the plots where hydrogel was used whereas minimum stomatal conductance (0.52 mole m^{-2} s^{-1}) recorded for control treatment during 2010-11 and this increase was 69 % (Table 4.4.30).

4.5 COMPETITIVE INDICES

4.5.1 Land Equivalent Ratio (LER)

Land equivalent ratio was calculated for sorghum and mungbean during both the growing years. LER for sorghum was 0.75 while for mungbean was 0.78 during 2010 and 0.80 and 0.79 during 2011, respectively. In intercrop sorghum occupied 75% and 80 % that is, 25% and 20% less area when comparing with the sole sorghum. Similarly mungbean covered 78% and 79% area, that is, 22% and 21% less than the solitary mungbean. However if LER of both the companion crops is added it gives the values of 1.53 and 1.59, indicating that 53% and 59% cropped area was increased respectively, over solitary cropping in both the years. Averaging the gain in area in the two years, it is evident that intrcropping helped to sow 56% more area in the same period of time than solitary cropping. These results reflected that 53 to 59 % more area would be needed for sole cropping system than intercrop cropping system for cultivation of sorghum and mungbean.

LER judge the performance of land used for intercropping in comparison to sole cropping. It is useful tool to overcome the problem of decreasing available area for cultivating field crops due to other uses and desertification of arable lands. Since in our studies the LER recorded was more for intercropping compared to sole depicting the benefits of intercropping in term of land use. The benefits of LER was earlier concluded by Mead and Willy (1980) who reported higher land area required for sole crop cropping pattern compared to intercrop cropping system. Similarly, work of Aal, (1991) and Saeed et al., (1999) confirmed highest LER for intercropping compared to mono-cropping. Meanwhile, Bismillah *et al*. (2001) depicted that comparative benefits between two cropping system could be depicted by LER.

The cropping system having highest LER might be considered better compared to one having lowest LER. Since LER is the indicator which could be used to check influence of intercropping on the cropping system. The positive inter-specific interference of crops in the intercropping could be checked by value of LER and if value of LER becomes higher than 1.0 it indicates the intensive influence of intercropping. Similar results were concluded by Dariush, *et al.*, (2006) while Kutrata, (1986) was of the view that an LER=1 indicates no difference between the area under intercrop and monocultures while if LER>1 confirms the advantage of intercrop compared to monoculture. Meanwhile he elaborated that if LER is 1.2 than it depicted 20% greater area requirements by sole cropping compared to intercropping to have same yield.

Kebebew, (2014) evaluated intercropping effect on yield components of intercrop crops? compared to sole cropping and concluded that LER remained highest for intercropping compared to mono-cropping. He further confirmed that productivity of intercropping could be easily evaluated by LER.

4.5.2 Relative Crowding Coefficient (RCC)

Relative Crowding Coefficient (K = {($K_{sorghum}$) ($K_{mungbean}$)} and Partial Relative Crowding Coefficients was derived for intercropped sorghum ($K_{sorghum}$) and mungbean ($K_{mungbean}$) during both the growing years (Fig 2). Higher value of partial relative crowding coefficient was calculated for mungbean ($K_{mungbean}$) than that of sorghum ($K_{sorghum}$). For intercropped mungbean higher $K_{mungbean}$ (1.46) was obtained during 2011 while lower $K_{mungbean}$ (1.29) was recorded during 2010. In the same way for intercropped sorghum $K_{sorghum}$was 0.99 during 2011 and 0.98 in 2010. The value of K {($K_{sorghum}$) ($K_{mungbean}$)} for 2010 was 1.27 and 2011 1.45. The K> 1during both the years showed that a yield advantage was obtained from the intercrop system. The yield advantage during 2010 was 27% and 45% in 2011 over the solitary crops.

The efficiency and financial benefits of systems like intercropping could be easily depicted by different competition functions which includes relative crowding coefficient (RCC) (Dhima *et al.,* 2007). The mungbean was emerged as dominant crop because of its highest RCC compared to sorghum during both years. The results of Kutrata, (1986) confirmed our findings who concluded that system efficiency might be evaluated by RCC and other efficiencies indicators. The earlier results of field study by Dhima *et al., (*2007) about use of vetch–cereal mixtures was evaluated by using RCC and other intercropping indices like aggressivity (A), actual yield loss (AYL), monetary advantage index (MAI), and intercropping advantage (IA). They concluded that LER and K values remained highest in intercropping compared to sole cropping showing, maximum potential of intercropping to exploit available resources in optimum way. The benefits of intercropping were evaluated by Ghosh, (2004) who studied intercropping legumes with non-legumes crops in the semi-arid region. They concluded that competition and economics of legume based intercropping system remained highest compared to mono-cropping. Since efficiency of system could easily be checked by land equivalent ratio (LER) and relative crowding coefficient (RCC) therefore in their findings they recorded highest LER and RCC for intercropping compared to sole cropping.

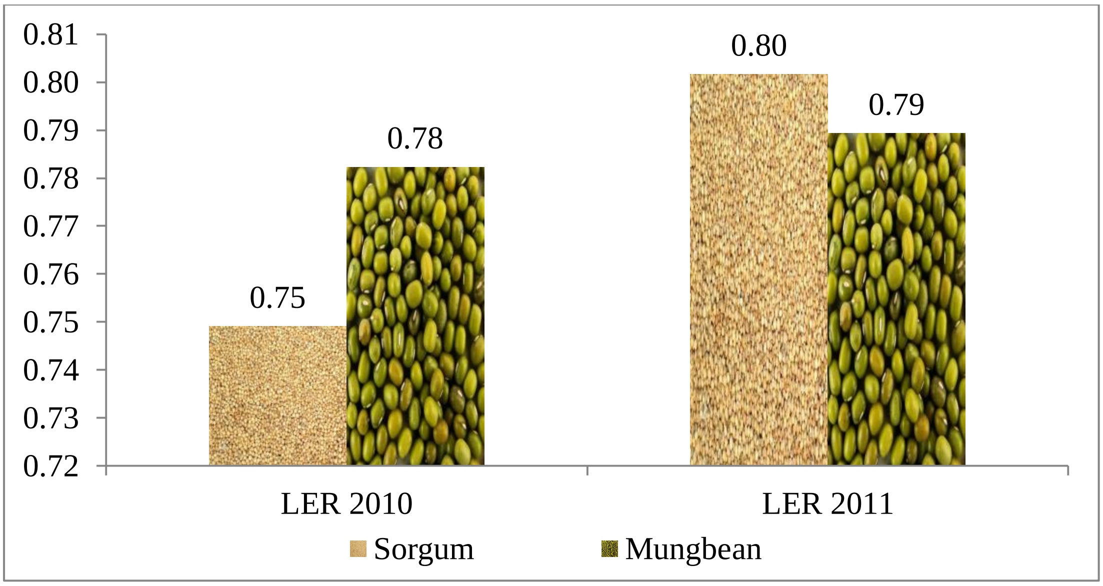


Fig 4.2 Average values for Land Equivalent Ratiofor Soghum/Mungbean as affected by intercropping

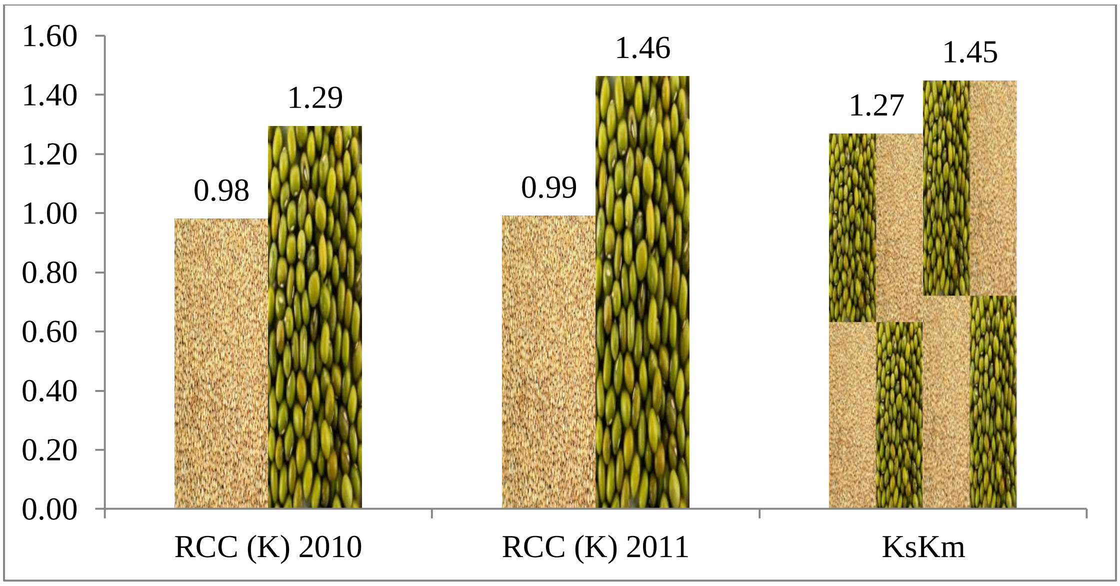


Fig 4.3Average values for Relative Crowding Coefficient for Sorghum/Mungbean as affected by intercropping

4.5.3 Aggressivity

Aggressivity is the index to compare two crops used in intercropping for estimating the competitive relationship. The data showed that in 2010 $A_{sorghum}$ was 1.66 with positive sign, where as $A_{mungbean}$ was 1.66 with negative sign. It was an indication that sorghum was dominant species when intercropped with mungbean and captured more resources aggressively. On the other hand, during 2011 reverse trend was noted, that is $A_{sorghum}$ was -0.62 and $A_{mungbean}$was +0.62, thus revealing the dominance of mungbean over sorghum. This reversal in the trend could be attributed to the difference in rainfall of both the years. During 2010, 300 mm was recorded as compared to 330 mm in 2011 (Fig 3.2 a) the lower rainfall in 2010 resulted in lower soil moisture, thus initiating stronger competition for soil water, which gave competitive advantage to sorghum ($A_{sorghum}$ = 1.66) to dominate in case of intercrop, suppressing mungbean ($A_{mungbean}$ = -1.66). Nonetheless, during 2011, much higher rainfall was received providing sufficient soil moisture for the growth of both the crops, reducing intercrop competition consequently the aggressivity value was decreased. Under favorable conditions mungbean was not suppressed by sorghum and proliferated well and exhibited positive aggressivity ($A_{mungbean}$ = +0.62) as compared to the negative value for sorghum ($A_{sorghum}$ = -0.62).

The use of aggressivity as a criterion to evaluate the comparative behavior of intercropping with sole crop was earlier depicted by Yilmaz *et al*., (2008). Their work concluded that different planting patterns like intercropping and sole cropping could be easily evaluated by indices like aggressivity.Cereals (maize, sorghum, and pearl millet) were also the dominant species in groundnut–cereal intercropping systems (Ghosh, 2004). Similarly, for mustard–legume intercropping, aggressivity was higher for mustard in all mixtures than for legume (Banik et al., 2000). In our studies positive aggressivity was calculated for sorghum which revealed that sorghum is dominant crop compared to legume crop. Similar to our findings Ghosh, 2004; and Dhima *et al*., 2007 concluded that cereals crops have positive aggressivity compared to legume crops which was because of exhaustive potential of cereals like sorghum. The use of indices like aggressivity, land equivalent ratio, relative crowding coefficient, competitive ratio, actual yield loss, monetary advantage, and intercropping advantage might be recommended for evaluation between sole and intercropping as concluded by Agegnehu *et al*., (2006) and Banik *et al*., (2006).

4.5.4 Competitive Ratio (CR)

Competitive ratio is also an index to estimate the competitive ability for crops used in intercropping. Competitive ratio of sorghum was 0.96 and mungbean was 1.04 during 2010 compared to 1.02 and 0.98 in 2011, respectively. During 2010 higher competitive ratio recorded for mungbean (1.04) than sorghum (0.96) indicated that mungbean dominated by 4% over sorghum which proved to a weaker companion to the same extent. Nevertheless, during 2011 higher competitive ratio was recorded for sorghum (1.02) while lower competitive ratio (0.98) was obtained for mungbean (fig 4), meaning that in the interspecific competition sorghum dominated by 2% over mungbean which was recessive companion by same percentage, during the second year. This could explained in the light of weather data (Fig 3.2), as during 2010 growing season, the rainfall received over the experimental field was 300 mm as compared to 330 mm in 2011.

The benefit of use of CR as criteria to check the performance of the individual crop was earlier evaluated by Ghosh, (2004). He concluded that CR is better criteria compared to RCC (relative crowding coefficient) since higher RCC determined only crop yield advantage. However, with CR determines the competitive advantage between two systems. It is an important way to check the degree with which one crop is going to compete with the other crop. Higher CR values for mungbean during first year indicates that mungbean is more competitive than sorghum while opposite trend during second year depicted sorghum as competitive crop. The CR is a good criteria to evaluate competition among different crops in a system. Bhatti *et al*., (2006) in their findings depicted that competitive behavior of components crops in different systems could easily be evaluated by higher values of relative crowding coefficient, competitive ratio and positive sign of the aggressivity.

The advantage of use of different competitive indices to check competition among different components was earlier reported by different scientists in their findings (Sarkar and Chakraborty, 2000; Sarkar and Sanyl, 2000; Sarkar *et al*. 2001).

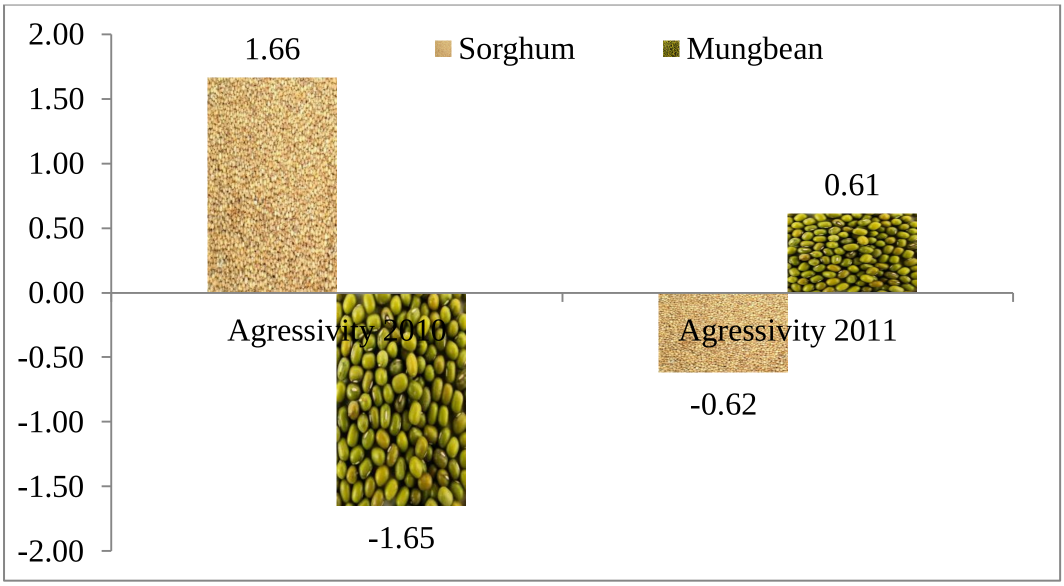


Fig 4.4Average values for Aggressivity for Soghum+Mungbean as affected by intercropping

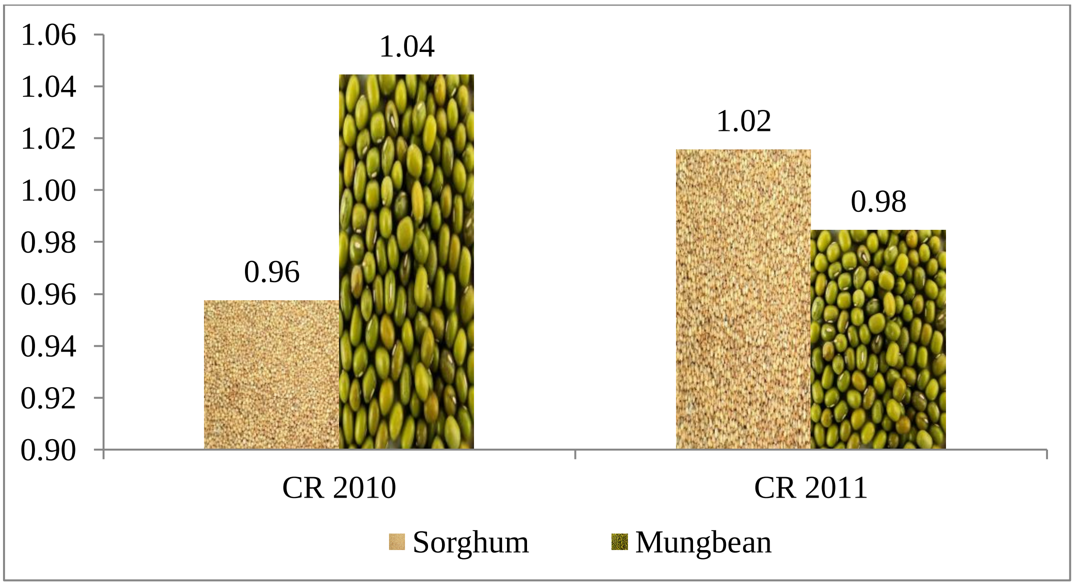


Fig 4.5 Average values for Competitive ratio for Soghum+Mungbean as affected by intercropping

4.5.5 Actual Yield Loss

Mungbean and sorghum showed loss in yield during both the years. Mungbean showed better results than sorghum. Higher actual yield loss was recorded during 2010 compared to 2011. Sorghum when intercropped with mungbean gave 25 % actual yield loss during 2010 while during 2011 sorghum actual yield loss was 20 %. In the same way, mungbean also reduced its yield when intercropped with sorghum (Fig 5). During 2010 the actual yield loss for mungbean used for intercropping system was 22 % and during 2011 mungbean actual yield loss was 21 %. Saban *et al.*, 2008 reported yield loss of legumes under intercropping system was due to competition for light and resources. The competition between and within component crops and species behavior could be best depicted by actual yield loss (AYL) (Banik *et al.*, 2000). In present studies AYL remained high for both crops in intercropped system compared to sole cropping which was due to competition for resources.

AYL of mungbean is greater than that of sorghum depicted that sorghum remained more competitive and resistant to yield loss in intercropping.

Moreover, Banik et al. (2000) reported that the actual yield loss (AYL) index gave more precise information about the competition than the other indices between and within the component crops and the behavior of each species in the intercropping system, as it is based on yield per plant. The AYL is the proportionate yield loss or gain of intercrops in comparison to the respective sole crop, i.e., it takes into account the actual sown proportion of the component crops with its pure stand. In addition, partial actual yield loss (AYLvetch or AYLcereal) represent the proportionate yield loss or gain of each species when grown as intercrops, relative to their yield in pure stand. The AYL is calculated according to the following formula (Banik, 1996): The AYL can have positive or negative values indicating an advantage or disadvantage accrued in intercrops when the main objective is to compare yield on a per plant basis.

4.5.6 Intercropping Advantage (IA)

Intercropping advantage (IA) was recorded to estimate the economic feasibility of intercropping systems (Fig 6). IA value was more negative for 2010 while less negative for 2011.

IA values for sorghum was smaller during both the growing years than mungbean. Partial intercropping advantage value for sorghum during 2010 was -6.27 while during 2011 partial intercropping advantage value was -4.96 which showed that during first year yield loss was 6.27 % whereas, during 2011 sorghum yield loss was 4.96 %.

On the other hand, mungbean suffered higher yield loss during both the years. Intercropping advantage value for mungbean during 2010 and 2011 was -13.06 and -12.64 respectively which illustrated that during 2010 mungbean yield loss was 13.06 % (-13.06) and during 2011 yield loss was 12.64 % (-12.64). Sorghum being a taller crop had the benefit of higher canopy and was able to harvest more sun light than mungbean and also exerted some shading effect on the companion crop. Therefore, it suffered less in terms of AYL showing lower AI. Contrary to sorghum, mungbean having lower canopy suffered from shading effect of sorghum and could harvest

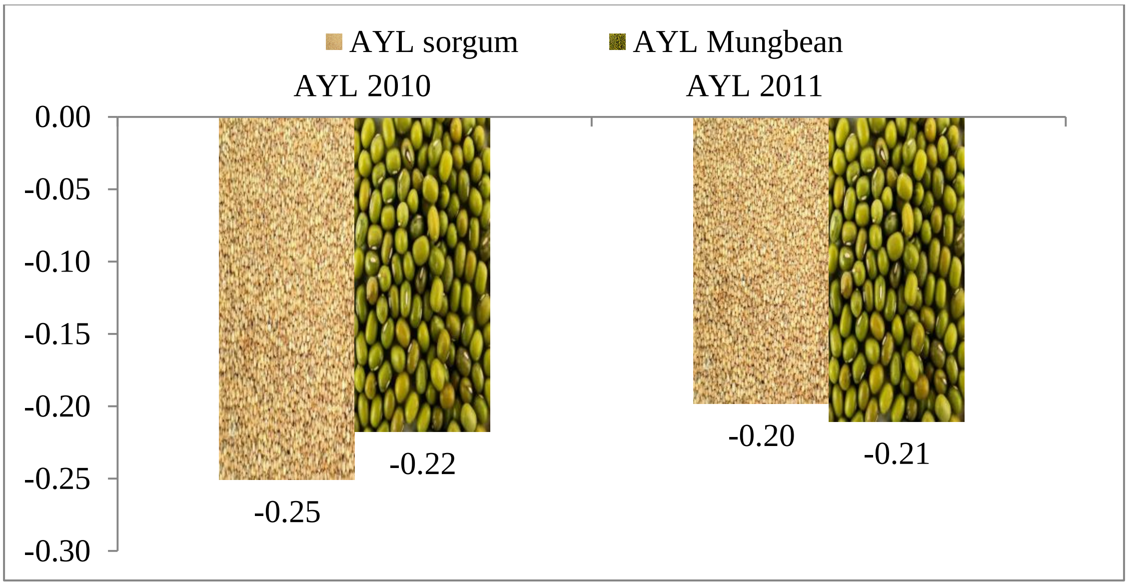


Fig 4.6 Average values for Actual Yield Loss for Soghum+Mungbean as affected by intercropping

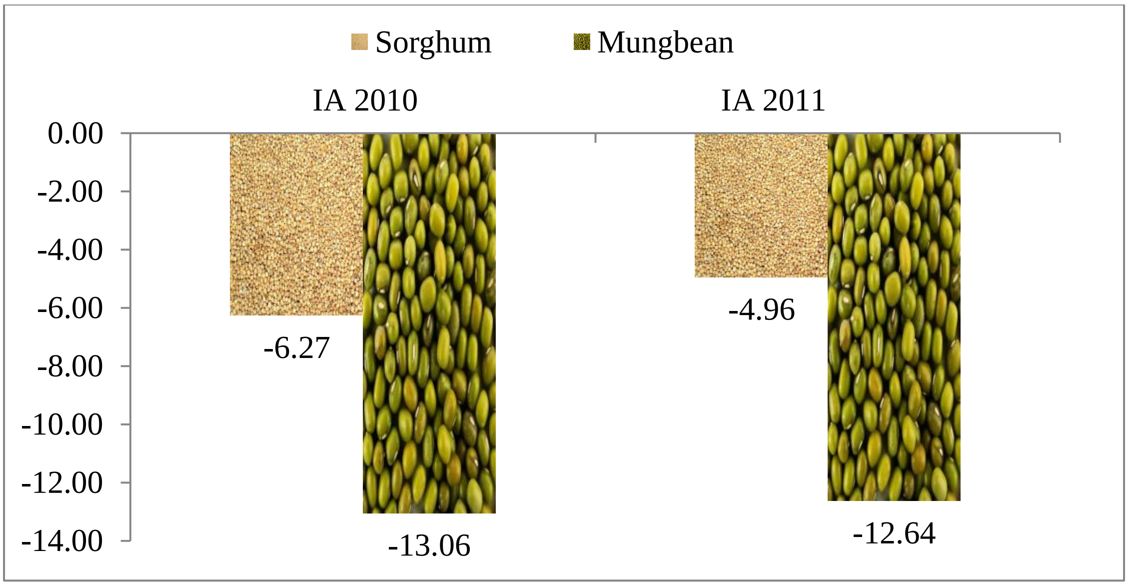


Fig 4.7 Average values for Intercropping Advantage for Sorghum+Mungbeanas affected by Intercropping system

limited sun light that was indicated in the form of higher AYL and IA as compared to sorghum.

IA is an indicator to check the economic feasibility of intercropping system as concluded by Banik *et al*., (2000). The IA depicted less yield loss for sorghum compared to mungbean and use of IA as important economic predictor was also confirmed in the findings of Yilmaz *et al*., (2008).

4.6 ECONOMIC ANALYSIS

The economic analysis of the experimental data is essential to look at the experimental results from farmer's point of view as they are often interested in the benefits and the cost of the technology and also like to know the risks in adopting new practices. Keeping in view the current scenario data was analysed for economic analysis. Partial budgeting was prepared for each soil additive under study to assess the cost and benefits related to each cropping system. Prices of inputs and outputs available from the local market were used for analyzing the data economically using the methodology as described by CIMMYT (1988).

4.6.1 Partial budget of different crops using soil additives under different cropping systems

Partial budgets of wheat for Fallow-Wheat cropping system using different soil additives have been represented in table 4.6.1. The highest gross benefits of Rs. 63823 (1US$ = Rs. 100) were taken from hydrogel soil additive while lowest gross benefits of Rs. 49312 were obtained from control under Fallow-Wheat cropping system. According to data, total cost that varied from Rs. 29055 for control to 37868 for FYM under Fallow-Wheat cropping system. Regarding the net benefits, hydrogel gave maximum net benefits of Rs. 30018 and lowest net benefits of Rs. 17191 was recorded from FYM.

Similarly, partial budgets of wheat for Mungbean-Wheat cropping system using different soil additives have been represented in table 4.6.2. The gross benefits of mungbean under Mungbean-Wheat cropping system when pooled for years ranged from Rs. 76320-80446 and for wheat ranged from Rs. 50995-63161. According to data, total cost that varied from Rs. 16508 for control to 25321 for FYMfor Kharif under Mungbean-Wheat cropping system while under Rabi it was ranged from 25055 for control and 37868 for FYM. Regarding the net benefits, for mungbean control treatment gave highest net benefits of Rs. 59812 and lowest net benefits of Rs. 58517 were recorded from gypsum whereas, for wheat under Rabi, hydrogel gave maximum net benefits of Rs. 29356 and lowest net benefits of Rs. 18202 was recorded from FYM.

In the same way partial budgets of wheat for Sorghum-Wheat cropping system using different soil additiveshas been represented in table 4.6.3. The gross benefits of sorghum under Sorghum-Wheat cropping system when pooled for years ranged from Rs. 22424-23468 and for wheat ranged from Rs. 49506-62826. According to data, total cost that varied from Rs. 19223 for control to 28035 for FYMfor sorghum under Sorghum-Wheat cropping system while for wheat it was ranged from 29055 for control and 37868 for FYM. Regarding the net benefits, for sorghum control treatment gave highest net benefits of Rs. 3201 and lowest net benefits in the form of loss of

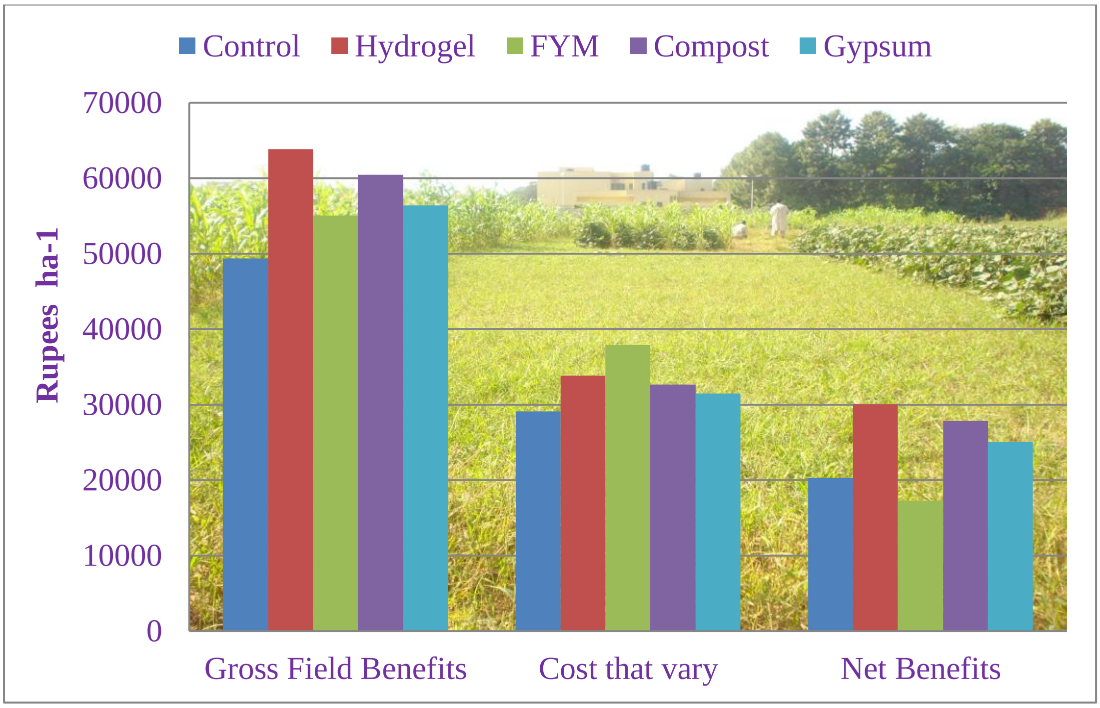


Fig 4.8 Partial budget analysis of Fallow-Wheat Cropping System

Table 4.6.1Partial budgets of wheat for Fallow-Wheat cropping system using different soil additives

Soil Additives	Rabi		
	Gross Field Benefits	Cost that vary	Net Benefits
Control	49312	29055	20257
Hydrogel	63823	33805	30018
FYM	55058	37868	17191
Compost	60445	32661	27783
Gypsum	56405	31430	24975

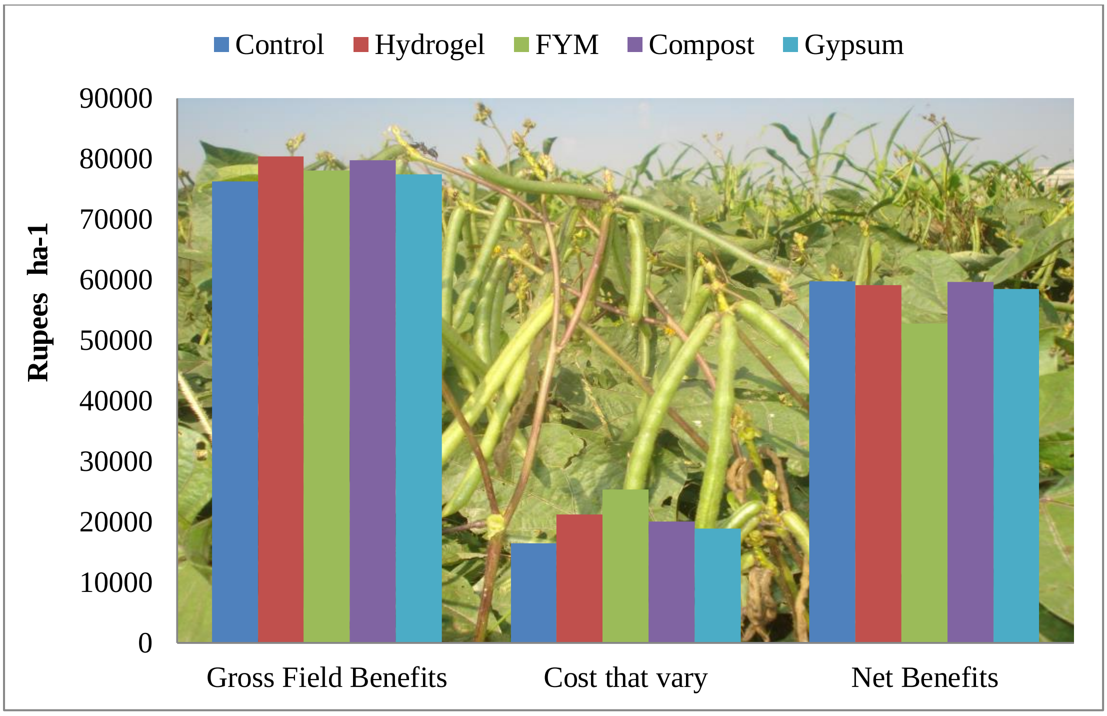


Fig 4.9 Partial budget analysis of Mungbeanunder various soil additives in Mungbean-Wheat Cropping System

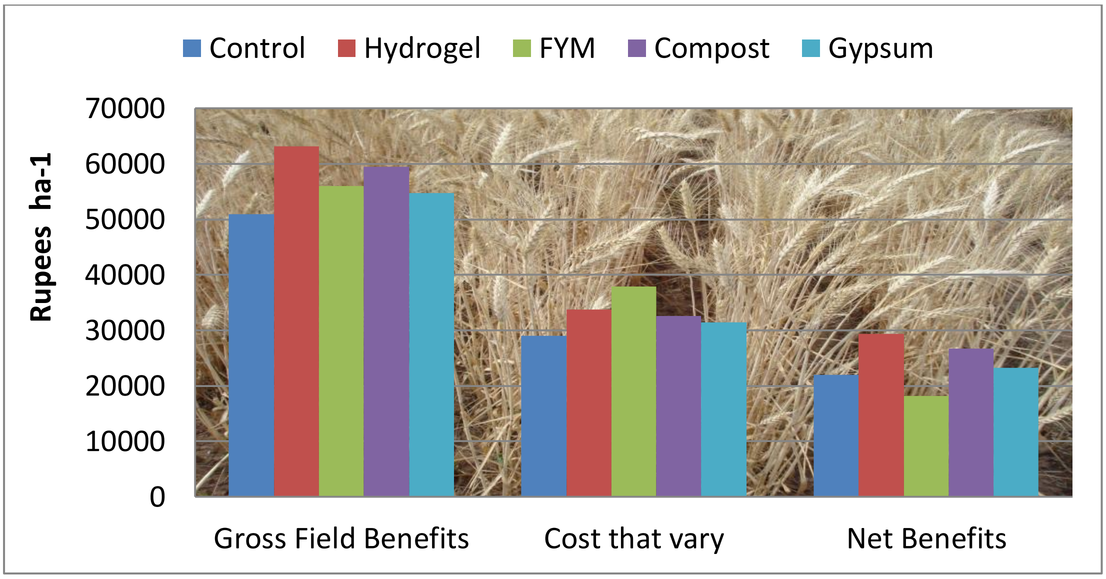


Fig 4.10 Partial budget analysis of wheat under various soil additives in Mungbean-Wheat Cropping System

Table 4.6.2 Partial budget analysis of Mungbean-Wheat Cropping System for summer (Kharif) and winter (Rabi) Seasons

Soil Additives	Kharif		
	Gross Field Benefits	Cost that vary	Net Benefits
Control	76320	16508	59812
Hydrogel	80446	21258	59187
FYM	78106	25321	52785
Compost	79776	20114	59662
Gypsum	77400	18883	58517
	Rabi		
Control	50995	29055	21940
Hydrogel	63161	33805	29356
FYM	56069	37868	18202
Compost	59436	32661	26774
Gypsum	54723	31430	23293

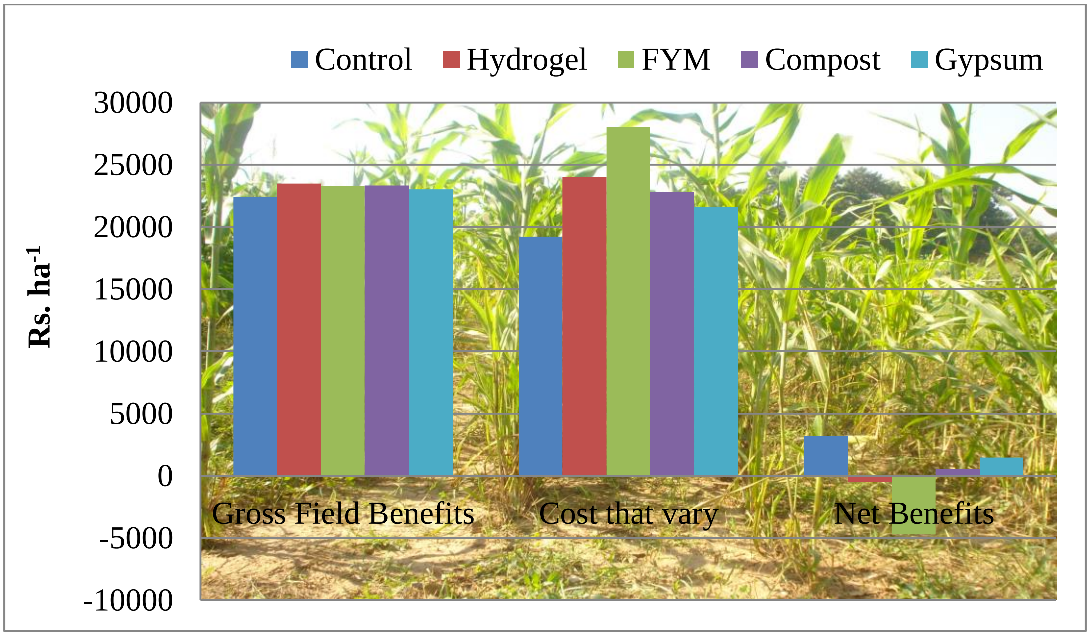


Fig 4.11 Partial budget analysis of sorghum under various soil additives in sorghum-Wheat Cropping System

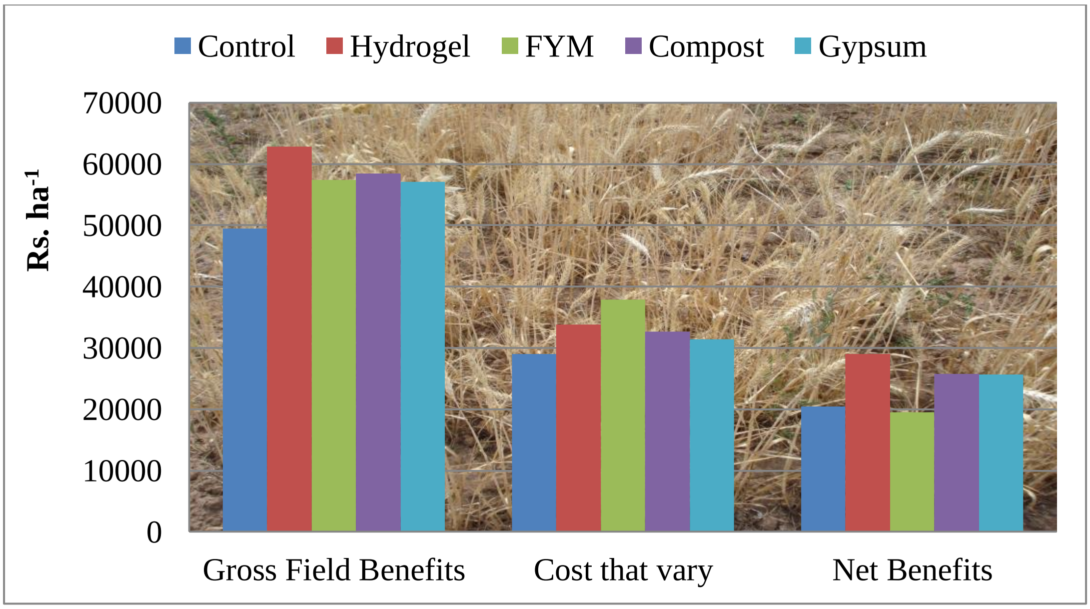


Fig 4.12 Partial budget analysis of wheatunder various soil additives in sorghum-Wheat Cropping System

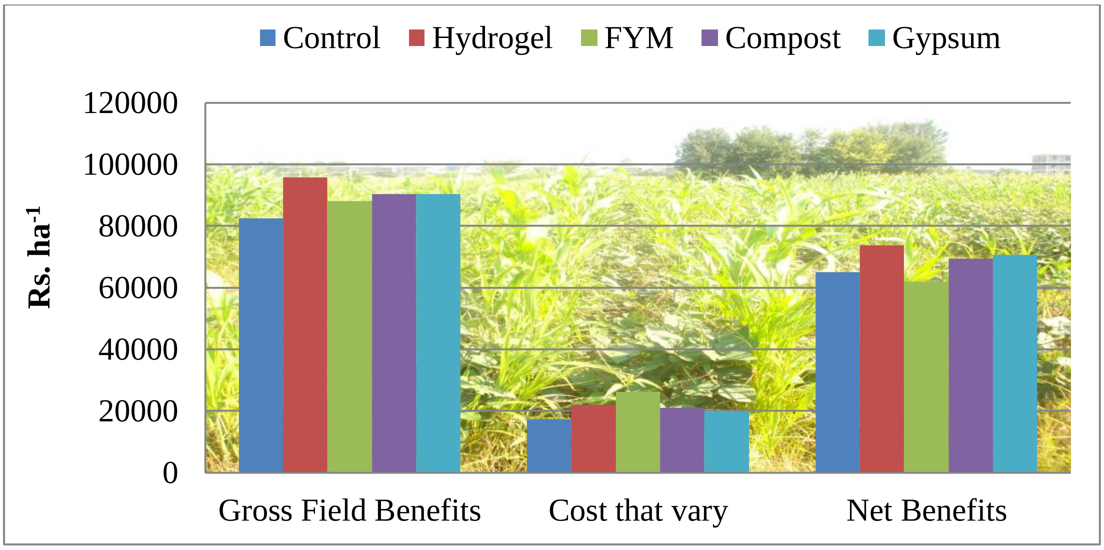


Fig 4.13 Partial budget analysis of intercrops under various soil additives in sorghum/mungbean-wheat cropping System

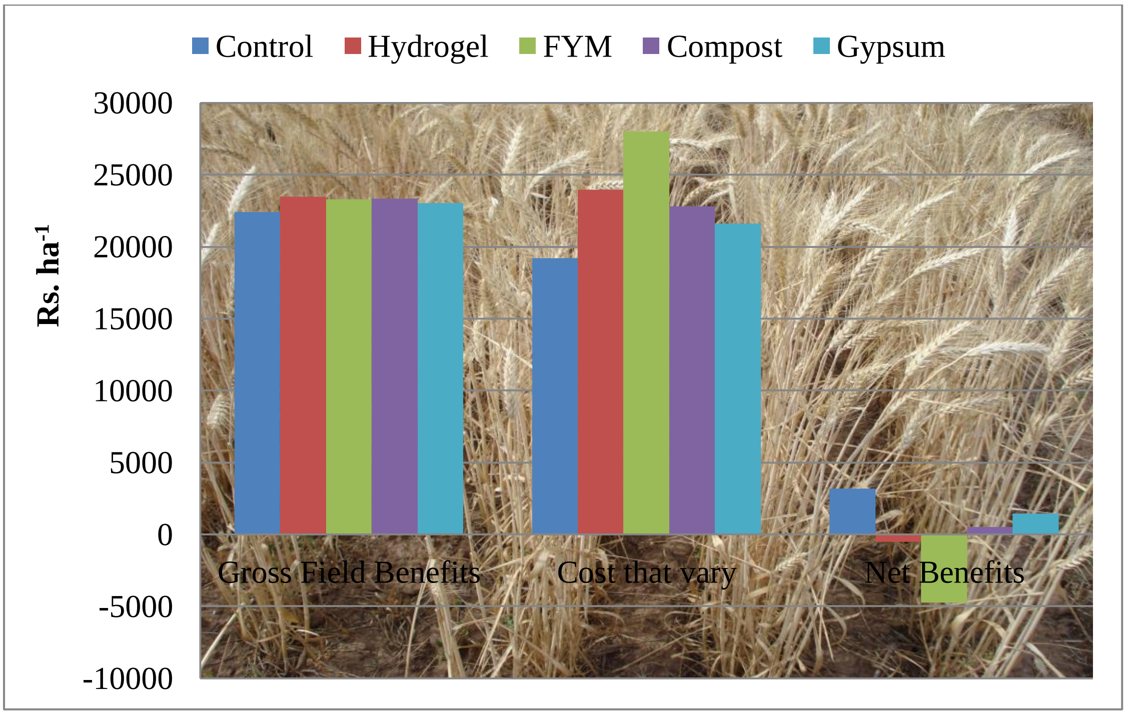


Fig 4.14 Partial budget analysis of wheat under various soil additives in sorghum/mungbean-wheat cropping System

Table 4.6.3 Partial budget analysis of Sorghum-Wheat Cropping System for summer (Kharif) and winter (Rabi) Seasons

Soil Additives	Kharif		
	Gross Field Benefits	**Cost that vary**	**Net Benefits**
Control	22424	19223	3201
Hydrogel	23468	23973	-505
FYM	23296	28035	-4739
Compost	23342	22829	512
Gypsum	23031	21598	1433
	Rabi		
Control	49506	29055	20451
Hydrogel	62826	33805	29021
FYM	57416	37868	19548
Compost	58425	32661	25763
Gypsum	57078	31430	25648

Table 4.6.4 Partial budget analysis of Mungbean/Sorghum-Wheat Intercrop Cropping System for summer (Kharif) and winter (Rabi) Seasons

Soil Additives	Kharif		
	Gross Field Benefits	Cost that vary	Net Benefits
Control	82386	17365	65021
Hydrogel	95814	22115	73699
FYM	88084	26178	61906
Compost	90394	20972	69422
Gypsum	90285	19740	70545
	Rabi		
Control	49974	29055	20919
Hydrogel	63894	33805	30089
FYM	54385	37868	16517
Compost	59771	32661	27110
Gypsum	57078	31430	25648

Rs. 4739 were recorded from FYM whereas, for wheat hydrogel gave maximum net benefits of Rs. 29021 and lowest net benefits of Rs. 19548 was recorded from FYM.

Similarly, partial budgets of wheat, mungbean and sorghum for Mungbean/Sorghum-Wheat intercrop cropping system using different soil additiveshas been represented in table 4.6.4. The gross benefits of mungbean and sorghum under Mungbean/Sorghum-Wheat intercrop cropping system when pooled for years ranged from Rs. 82386-95814and for wheat ranged from Rs. 49974-63894. According to data, total cost that varied from Rs. 17365 for control to 26178 for FYM for mungbean + sorghum under Mungbean/Sorghum-Wheat intercrop cropping system while for wheat it was ranged from 29055 for control and 37868 for FYM. Regarding the net benefits, for mungbean + sorghum control treatment gave highest net benefits of Rs. 73699 and lowest net benefits of Rs. 61906 were recorded from FYM whereas, for wheat hydrogel gave maximum net benefits of Rs. 30089 and lowest net benefits of Rs. 16517 was recorded from FYM.

4.6.2Marginal Analysis of Different Cropping Systems

In the partial budget analysis total cost that vary and net benefit that each cropping pattern was calculated but did not compare the cost that vary with the net benefits. For such comparisons marginal analysis are required. Marginal analysis involved dominance analysis and marginal rate of returns. To determine most profitable cropping system and soil additives by comparing the costs that vary with the net benefits obtained (marginal analysis performed). In order to do dominance analysis

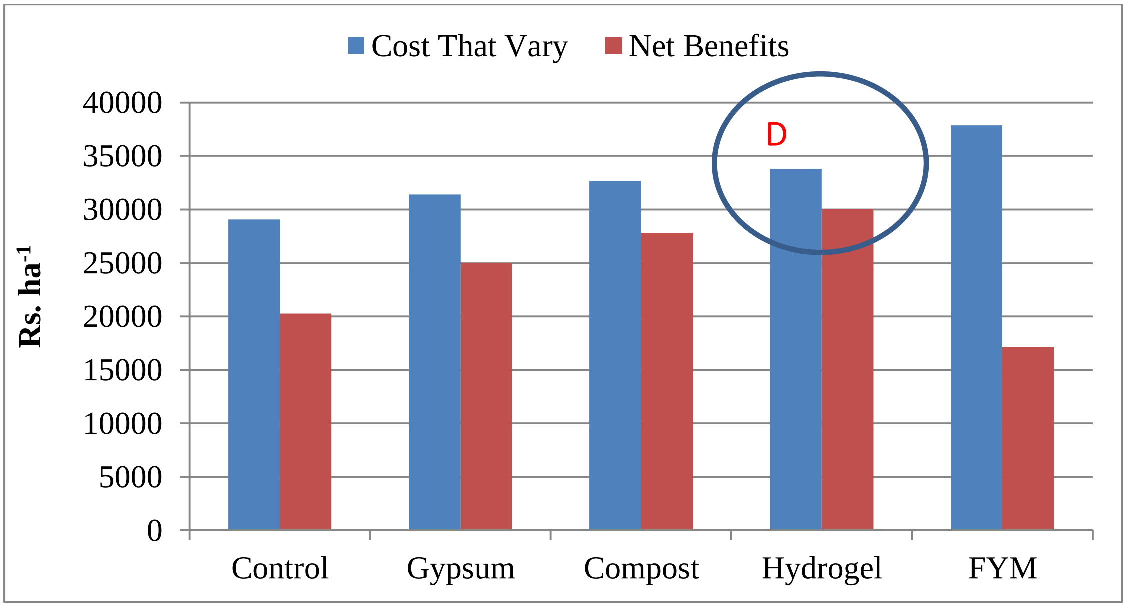


Fig 4.15 Dominance Analysis of various soil additives in Fallow-wheat cropping system

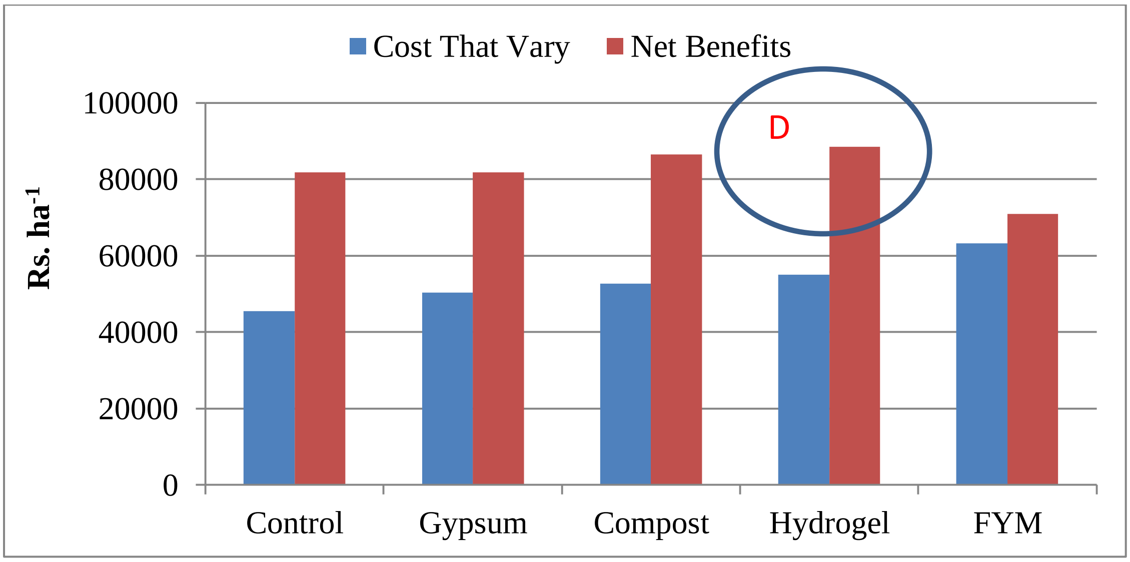


Fig 4.16 Dominance Analysis of various soil additives in Munbean-wheat cropping system

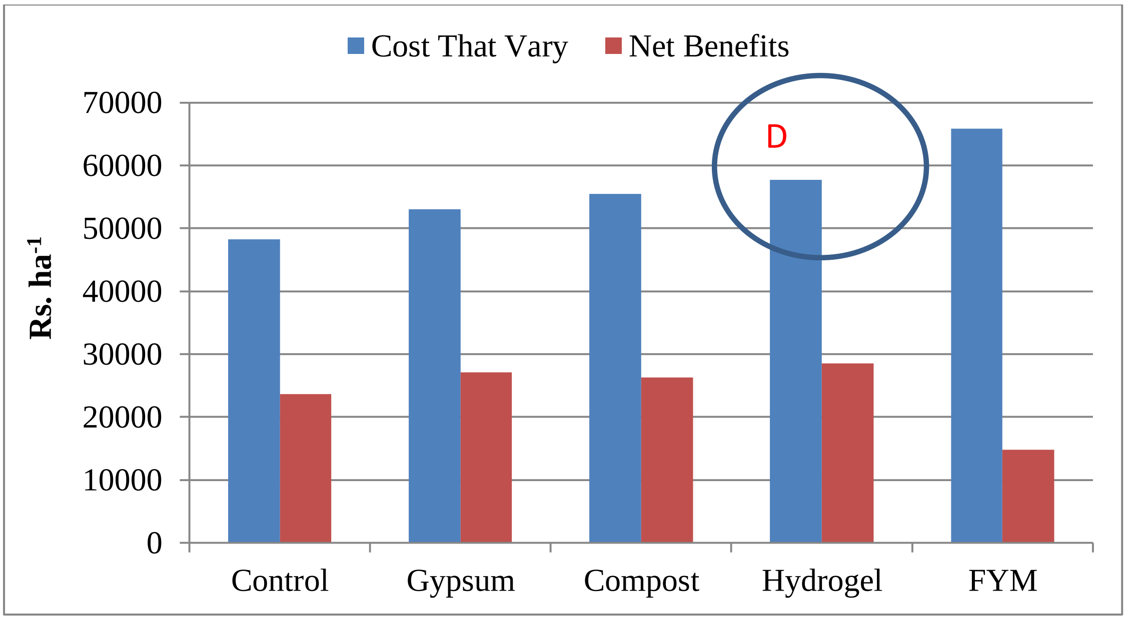


Fig 4.17 Dominance Analysis of various soil additives in Sorghum-Wheat System cropping system

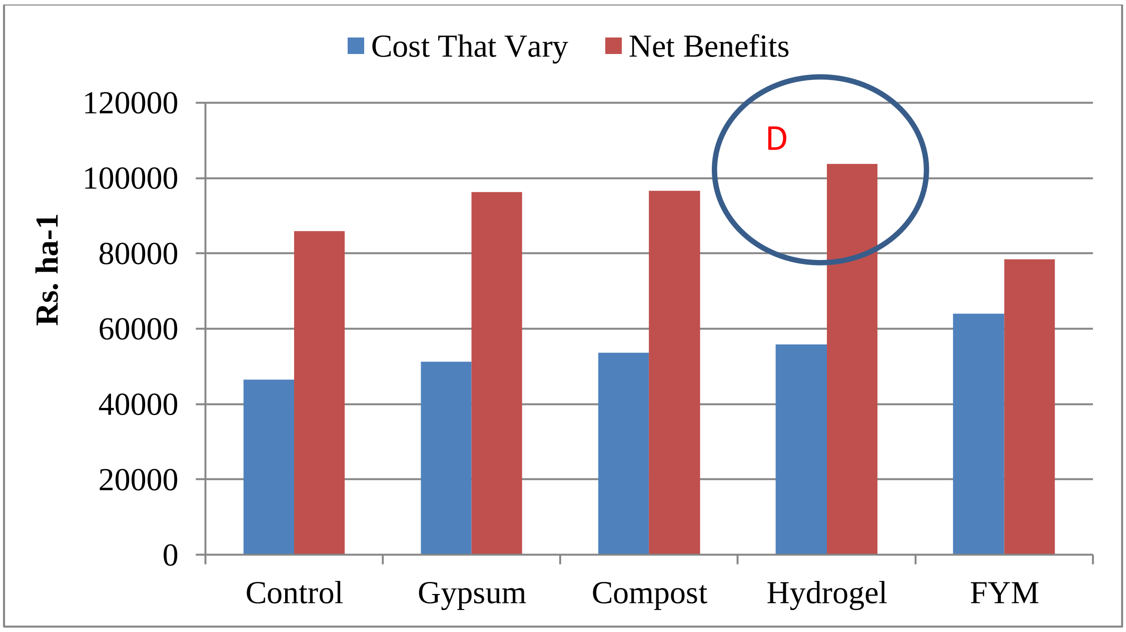


Fig 4.18 Dominance Analysis of various soil additives in Sorghum+Mungbean-Wheat cropping system

Table 4.6.5 Dominance analysis Fallow-Wheat Cropping System for summer (Kharif) and winter (Rabi) Seasons

Soil Additives	Cost That Vary	Net Benefits
Control	29055.1	20257.4
Gypsum	31430.1	24974.6
Compost	32661.3	27783.3
Hydrogel	33805.1	30017.9
FYM	37867.6	17190 D

Table 4.6.6 Dominance analysis Mungbean-Wheat Cropping System for summer (Kharif) and winter (Rabi) Seasons

Soil Additives	Cost That Vary	Net Benefits
Control	45563.2	81751.4
Gypsum	50313.2	81809.4
Compost	52775.7	86436.1
Hydrogel	55063.2	88543.8
FYM	63188.2	70986.6 D

Table 4.6.7 Dominance analysis Sorghum-Wheat Cropping System for summer (Kharif) and winter (Rabi) Seasons

Soil Additives	Cost That Vary	Net Benefits
Control	48277.8	23651.9
Gypsum	53027.8	27081.2
Compost	55490.3	26275.8
Hydrogel	57777.8	28515.7
FYM	65902.8	14809.43 D

Table 4.6.8 Dominance analysis Fallow-Wheat Cropping System for summer (Kharif) and winter (Rabi) Seasons

Soil Additives	Cost That Vary	Net Benefits
Control	46420.5	85939.5
Gypsum	51170.5	96192.6
Compost	53633	96532.3
Hydrogel	55920.5	103787
FYM	64045.5	78423.23 D

cropping systems were arranged in the ascending order of increasing variable costs. A cropping pattern was dominated if its variable costs were higher than the preceding cropping system, but its benefits were lower. Such cropping system was termed as dominated cropping system and denoted by “D”.

The dominance analysis for Fallow-Wheat cropping system using different soil additives represented in table 4.6.5.The results depicted that FYM soil additive dominated from other soil additives under Fallow-Wheat cropping system. The results indicated that compost and hydrogel are more profitable than other soil additives under Fallow-Wheat cropping system. Similarly, the dominance analysis for Mungbean-Wheat cropping system under different soil additives has been represented in table 4.6.6.The results depicted that FYM soil additive dominated from other soil additives under Mungbean-Wheat cropping system. The results indicated that hydrogel and compost are more profitable than other soil additives under Mungbean-Wheat cropping system. Similarly, the dominance analysis for Sorghum-Wheat cropping system under different soil additives has been represented in table 4.6.7.The results depicted that FYM soil additive dominated from other soil additives under Sorghum-Wheat cropping system. The results indicated that hydrogel and gypsum are more profitable than other soil additives for Sorghum-Wheat cropping system. Whereas, the dominance analysis for Mungbean/Sorghum-Wheat cropping system under different soil additives has been represented in table 4.6.8.The results depicted that FYM soil additive dominated from other soil additives under Mungbean/Sorghum-Wheat intercrop cropping system. The results indicated that hydrogel is more profitable than other soil additives under Mungbean/Sorghum-Wheat intercrop cropping system.

To further refine the cropping system recommendations, marginal rate of returns was calculated. The marginal rate of returns for Fallow-Wheat cropping system under different soil additives has been represented in table 4.6.9.The analysis revealed that instead of control hydrogel soil additive was recommended for Fallow-Wheat cropping system. The marginal rate of returns (MRR) was highest for hydrogel (228 %), compared to other soil additives. This was mainly due to the differences in costs that vary, between soil additives were little but the differences in the net benefits were huge under cropping system.

The marginal rate of returns for Mungbean-Wheat cropping system under different soil additives has been represented in table 4.6.10.The analysis revealed that instead of control compost soil additive was recommended for Mungbean-Wheat cropping system. The marginal rate of returns (MRR) was highest for compost (187 %), compared to other soil additives. This was mainly due to the differences in costs that vary, between soil additives were little but the differences in the net benefits were huge under Mungbean-Wheatcropping system.

The marginal rate of returns for Sorghum-Wheat cropping system under different soil additives has been represented in table 4.6.11.The analysis revealed that instead of control hydrogel soil additive was recommended under Sorghum-Wheat cropping system while for compost a marginal net loss of Rs. 809 was calculated.The marginal rate of returns (MRR) was highest for compost (97.9 %), compared to other soil additives and for compost MRR of -32.7% was calculated. This was mainly due to

Table 4.6.9 Average marginal Rate of return for Fallow-Wheat cropping System

Soil Additives	Cost That Vary	Net Benefits	Marginal Net Benefit	Marginal Net Cost	MRR
Control	29055.1	20257.4			
Gypsum	31430.1	24974.6	4717.23	2375	198.62
Hydrogel	32661.3	27783.3	2808.63	1231.25	228.112
Compost	33805.1	30017.9	2234.63	1143.75	195.377
FYM	37867.6	17190 D			

Table 4.6.10 Average marginal Rate of return for Mungbean-Wheat cropping System

Soil Additives	Cost That Vary	Net Benefits	Marginal Net Benefit	Marginal Net Cost	MRR
Control	45563.2	81751.4			
Gypsum	50313.2	81809.4	58.025	4750	1.22158
Compost	52775.7	86436.1	4626.69	2462.5	187.886
Hydrogel	55063.2	88543.8	2107.76	2287.5	92.1426
FYM	63188.2	70986.60 D			

Table 4.6.11 Average marginal Rate of return for Sorghum-Wheat cropping System

Soil Additives	Cost That Vary	Net Benefits	Marginal Net Benefit	Marginal Net Cost	MRR
Control	48277.8	23651.9			
Gypsum	53027.8	27081.2	3429.3	4750.0	72.2
Compost	55490.3	26275.8	-805.4	2462.5	-32.7
Hydrogel	57777.8	28515.7	2239.9	2287.5	97.9
FYM	65902.8	14809.43 D			

Table 4.6.12 Average marginal Rate of return for Sorghum+Mungbean-Wheat cropping System

Soil Additives	Cost That Vary	Net Benefits	Marginal Net Benefit	Marginal Net Cost	MRR
Control	46420.5	85939.452			
Gypsum	51170.5	96192.59	10253.1	4750	215.856
Compost	53633	96532.34	339.75	2462.5	13.797
Hydrogel	55920.5	103787.3	7254.96	2287.5	317.157
FYM	64045.5	78423.23 D			

the differences in costs that vary, between soil additives were little but the differences in the net benefits were huge under Sorghum-Wheat cropping system.

On the other hand the marginal rate of returns for Mungbean/Sorghum-Wheat intercrop cropping system under different soil additives has been represented in table

4.6.12.The analysis revealed that instead of control hydrogel soil additive was recommended for Mungbean/Sorghum-Wheat intercrop cropping system. The marginal rate of returns (MRR) was highest for hydrogel (317 %), compared to other soil additives and for compost MRR of only 13 % was calculated. This was mainly due to the differences in costs that vary, between soil additives were little but the differences in the net benefits were huge under Mungbean/Sorghum-Wheat cropping system.

On the basis of budget analysis Mungbean/Sorghum-Wheat intercrop cropping system should be recommended to the farming community of arid zone of Pakistan. In the same way, soil additives are also helping to increase the economic status of the farming community. Hydrogel and compost should be used as soil additives to increase soil water holding capacity which will ultimately lead to better crop stand and good yield.

SUMMARY

Soil moisture deficiency is the major abiotic constraint for successful crop production in rainfed areas of Pakistan. Rainfall is the only source of soil moisture for crops but is highly variable in its amount, distribution and intensity. The observed and projected rainfall statistics have indicated further shift from winter rainfall towards summer season. This will aggravate soil moisture stress during early to mid-wheat growing season leading to further decrease in wheat productivity. However, projected increase in summer rainfall offers an opportunity to conserve it in soil profile for subsequent use for winter season crops. Various techniques can be used to conserve soil moisture and organic/ inorganic soil additives could be one of the feasible and environmentally safe option for water retention in soil profile. Some of them have been tested for conservation of rain water in soil namely gypsum, farm yard manure and green manures. However, comprehensive data on compost and hydrogel usage is not available under various cropping systems under local conditions. The present studies was, therefore, conducted at research area of PMAS, Arid Agriculture University Rawalpindi to:1) test various soil additives for soil moisture conservation under different cropping systems, 2) find out an appropriate cropping system for efficient resource utilization and increase production per unit area and 3) compare the profitability of different soil additives and cropping systems. The cropping systems included summer fallow-wheat, mungbean-wheat, sorghum-wheat, and sorghum + mungbean–wheat. The field experiment was laid out in Randomized Complete Block Design with split plot arrangements keeping cropping systems in main plots and soil additives in subplots. Soil additives i.e. farm yard manure, gypsum,

compost and hydrogel (Qemisoyl) were applied @ 25 t ha^{-1}, 2.5 t ha^{-1}, 0.75 t ha^{-1} and 15 kg ha^{-1} respectively, before the onset of monsoon.

1. Before conducting a comprehensive field trial involving various cropping systems and soil additives, a small laboratory study was conducted to screen out the best soil additives as well as their combinations for soil moisture conservation. The data developed on plant available water extracted from soil moisture characteristic curves at various tension levels (33 to 1500 kpa), showedthe highest plant available water content (0.14m^3 m^{-3}) under Qemisoyl (@ 15 kg ha^{-1})and was followed by compost (0……m^3 m^{-3}) when used @ 0.75 Mg ha^{-1}. The data revealed that soil moisture contents were statistically same for the soil additives when applied singly or in combinations. Least water content of 0.13 m^3 m^{-3} at permanent wilting point was observed in soil with no additive. Overall, plant available water contents measured in soil samples treated with additives were higher than samples with no additive.
2. Based on the results of the laboratory trial, a two-year field study was conducted in semi-arid region of Punjab to check the performance of soil additives under various cropping systems. The cropping systems included Mungbean-Wheat, Sorghum-Wheat, Sorghum + Mungbean-Wheat and were also compared with the farmers' practice of Fallow-Wheat cropping system. The performance of four soil additives i.e Qemisoyl, Farm Yard Manure, Compost, Gypsum was evaluated under different cropping sequences. An additional control with no soil additive was maintained to have comparative data. The data on various soil and crop parameters i.e. soil moisture content, bulk density, crop growth, competitive relationships, yield and yield

components of crops and water use efficiency was collected to measure performance of various cropping systems. The data recorded was also used to identify the most profitable cropping system as well as soil additive for farming communities of rainfed areas for improving crop productivity at farm level. The average results of tow-year field study are summarized as below:

i.) Soil moisture at the time of planting was taken as a criterion to measure the efficiency of soil additives for soil moisture conservation. The data showed that Hydrogel (Qemisoyl) conserved higher moisture content (16.42%) in the soil profile at the time of wheat sowing as compared to control (12.80%). It was followed by compost (14.55%), FYM (14.30%) and Gypsum (13.23%). Mungbean-Wheat cropping system had slightly higher soil moisture content (15.1%) as compared to farmers' practice of Fallow-Wheat system (14.4%). Minimum soil moisture was recorded in Sorghum-Wheat system (13.2%). The moisture content in intercropping system was at par with control (fallow-wheat). Winter post-harvest soil water contents were recorded at the depth of 0-90 cm. All the soil additives under all the cropping systems during both years differed potentially for moisture contents. Use of soil additives enhanced soil water retention and among the soil additives, the highest soil water contents was recorded for hydrogel (17.61%) with the lowest in control plots (14.9%). All the cropping systems differed potentially for soil moisture contents. The highest soil water contents were recorded for Mungbean-Wheat system (17.29%) and lowest were recorded for Fallow-Wheat system (15.23%). The soil moisture data showed superiority of hydrogel as most effective soil additive under legume-cereal intercrop cropping system.

ii.) The data regarding soil bulk density at summer plantation showed that soil additives depicted their difference for soil bulk density in the upper soil profile (0-30 cm). Among soil additives, the highest bulk density (1.45 Mg/m^3) was recorded under hydrogel treatment (1.36 Mg/m^3) whereas, the highest bulk density was recorded under Mungbean-Wheat and Sorghum-Wheat systems (1.45 Mg/m^3) and lowest was recorded under CS1 (Summer Fallow-wheat)(1.39 Mg/m^3), which was significantly lower than CS4 (Sorghum + mungbean- wheat)(1.40 Mg/cm3). Soil bulk density in the soil upper profile remained higher during 2011 than 2010.

iii.) Water use efficiency for both the summer seasons remained statistically non-significant. Among soil additives, the highest water use efficiency (1.39 kg/ha/mm) was recorded for hydrogel treatment followed by compost (1.35 kg/ha/mm) and FYM (1.34 kg/ha/mm) while the lowest water use efficiency was recorded in control plots (1.28 kg/ha/mm). Similarly, water use efficiency for summer plantation varied considerably under all the cropping systems. The highest water use efficiency was recorded for CS4 (2.71 kg/ha/mm) and it was potentially higher than CS2(Mungbean-wheat) (1.47 kg/ha/mm) while the lowest water use efficiency was recorded in CS3(Sorghum- wheat)(1.14 kg/ha/mm).

iv.) The winter (wheat) water use efficiency pattern was different from summer season. Among soil additives, the highest water use efficiency (13.54 kg/ha/mm) was recorded for gypsum treatment followed by FYM (13.33kg/ha/mm) while the lowest water use efficiency (12.87 kg/ha/mm) was recorded from the plots where compost was used (Table 4.5.1) whereas, water use efficiency for hydrogel (13.17 kg/ha/mm) and control (13.13 kg/ha/mm) treatments were at par with each other. Similarly, water use efficiency for wheat crop differed considerably under all the cropping systems. The highest water use efficiency was recorded for CS2 (13.61 kg/ha/mm) followed by CS3 (13.34 kg/ha/mm) and CS4 (13.26 kg/ha/mm) while the lowest water use efficiency was recorded under CS1 (12.62 kg/ha/mm).

v.) The data revealed higher crop growth rates in hydrogel treatment under Sorghum/mungbean-wheat cropping system. There was a significant variation among two years, cropping systems and soil additives for wheat crop growth rate at tillering, flag leaf and anthesis stages of wheat.

vi.) The interactive-effect of various soil additives and cropping systems on yield of crops was visible. Maximum mungbean seed yield (1071.8 kg/ha) was observed during 2011 for hydrogel while minimum seed yield (887.7 kg/ha) was recorded during 2010 for control treatment. Sole mungbean produced more seed yield (1089 kg/ha) as compared to the Mungbean-Sorghum intercrop cropping system (863 kg/ha) which was 26 % higher than the intercrop. During second year i.e. 2011 mungbean seed yield was 11 % higher (1028 kg/ha) than the first year (923 kg/ha) i.e. 2010. The highest sorghum grain yield (869 kg/ha) was observed under sole sorghum cropping system where hydrogel was used whereas, lowest sorghum grain yield (623 kg/ha) was recorded in the plots where Mungbean was intercropped in sorghum (Table 4.3.17). Hydrogel treatment under sole sorghum cropping system got 40 % higher sorghum grain yield than control treatment under

Mungbean-Sorghum intercrop cropping system. Maximum wheat grain yield (2796.5 kg/ha) was observed in plots where hydrogel was used and compost was at par with it during the second year. The effect of FYM and gypsum on wheat grain yield was comparable with each other during both years. The incorporation of hydrogel in soil showed 52% increase in wheat grain yield over the control which exhibited minimum grain yield (1828 kg/ha) during 2010-11. The data revealed that Sorghum-Mungbean intercropping system produced wheat (2424 kg ha^{-1}) at par with other systems implying that planting sorghum + Mungbean during summer season instead of keeping the land fallow did not reduce wheat production in subsequent winter when it was supported with application of Qemisoyl.

vii.) The values of competitive indices i.e. Land equivalent ratio, Relative crowding coefficient, and Competitive ratio indicated sorghum + Mung-Wheat intercropping system as the most competitive and resource efficient system. Actual yield loss and Intercropping Advantage indices indicated reduction in yield of crops as compared to sole but it was compensated by (intercropping) production of two crops from same piece of land. Therefore, the competitive indices data indicated an element of sustainability for dryland regions on account of improved resource use efficiency.

viii.) Partial budget analysis revealed Sorhgum + Mungbean-Wheat as most profitable cropping system; and Hydrogel as most profitable soil additive. The marginal analysis (MRR) revealed hydrogel as most profitable soil additive in all cropping systems except Mungbean-Wheat system where compost was found most profitable.

CONCLUSION

It can be concluded from the studied parameters like plant available soil water, soil moisture at saturation, field capacity and permanent wilting point, that Qemisoyl can be effectively used for retaining significant amount of water in rhizosphere which could be utilized to achieve higher crop productivity in severely vulnerable and drought prone ecology of rainfed areas. Furthermore, the combined use of various soil additives did not show any superiority over their sole application.

In the climate change scenario, inclusion of Sorghum and Mungbean as sole and intercrop may easily be fitted in farmers practice of Fallow-Wheat rotation, replacing fallow from the sequence in the area of study. This can help produce additional food in the same cropping period through efficient resource utilization by creating additional areas for Mungbean and Sorghum production through intercropping technique.

FUTURE RESEARCH RECOMMENDATIONS

For future, it can be recommended that considering the climate, soil type and agro-ecological zones, new more efficient and economical hydrogels may be developed and tested for moisture retention under different combinations of crops both for summer as well as winter for sole/intercropping systems.

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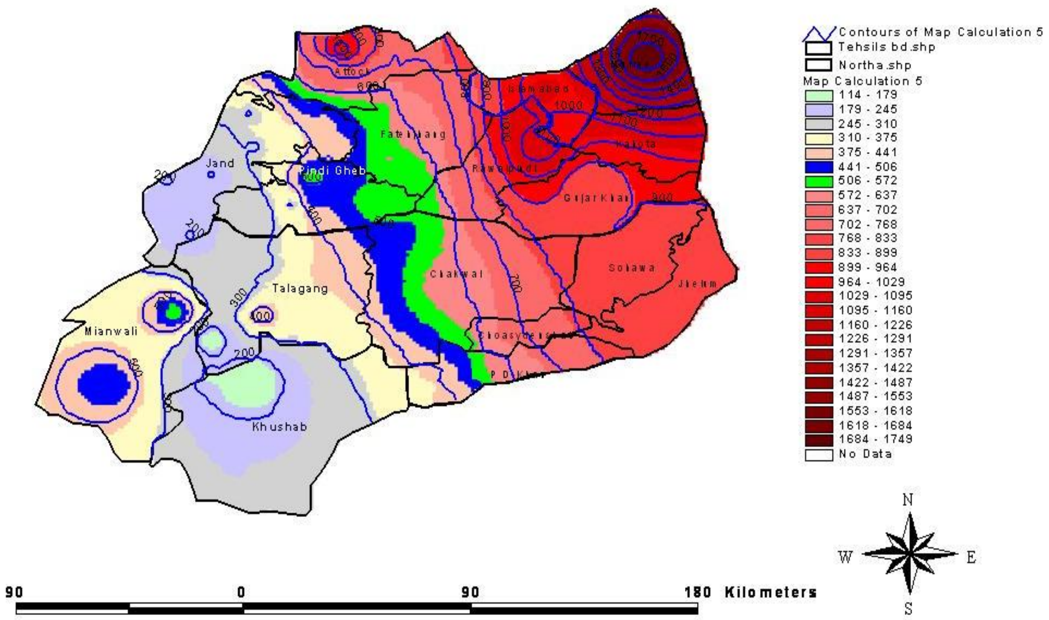
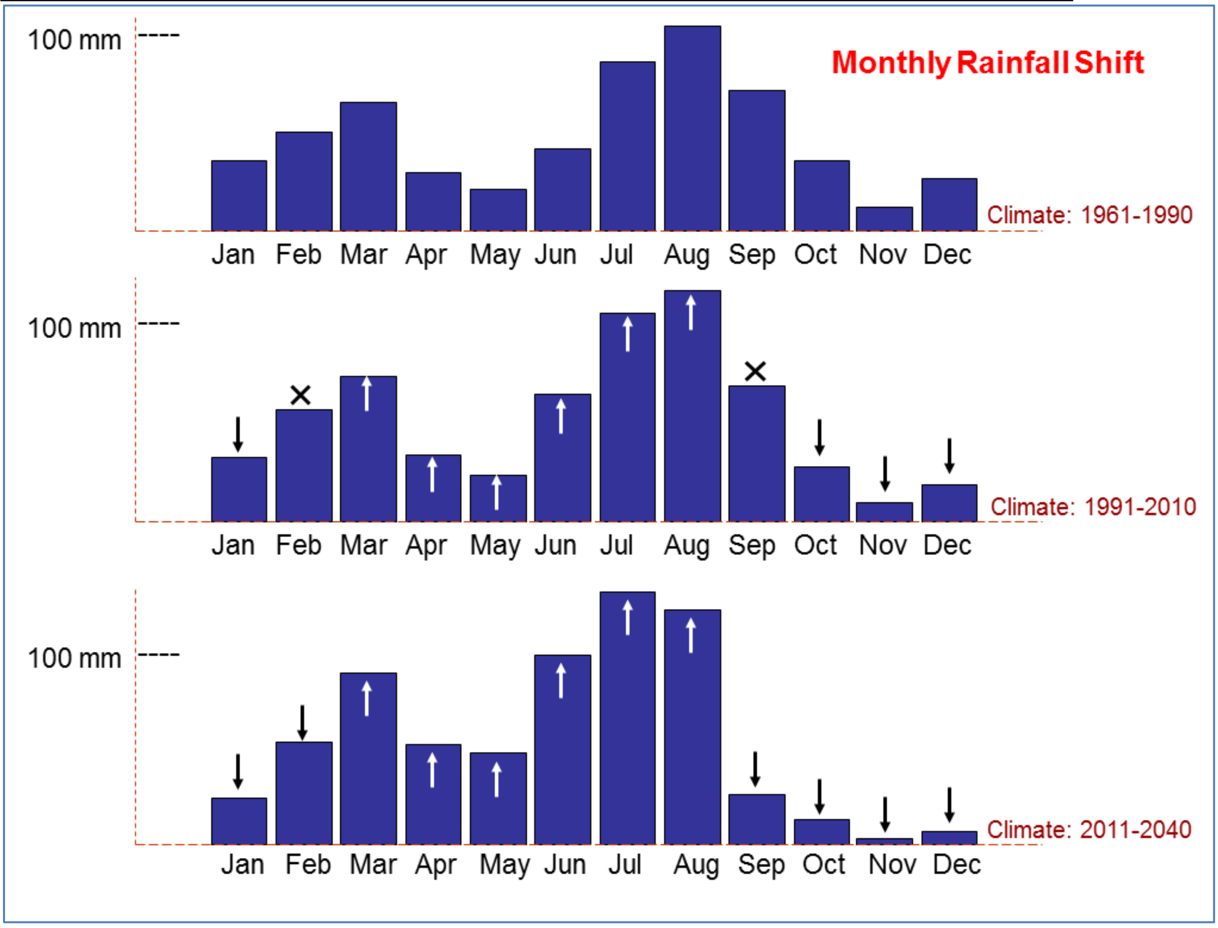
APPENDICES

Appendix-1 Isohyetal map of rainfed (dryland) areas of Punjab, Pakistan



Data source: SAWCRI, Chakwal, Pakistan

Appendix 2 Observed and projected trend in monthly rainfall in Pakistan



Data Source: Pakistan Meteorological Department

Appendix 3ANOVA table for Soil moisture content at summer sowing at the depth 0-30 cm

Source	DF	SS	MS	F	P
R	2	2.215	1.1077		
Y	1	63.948	63.948	19676.3	***
Error R x Y	2	0.006	0.0032		
CS	3	24.139	8.0463	48.81	***
Y x CS	3	201.382	67.1273	407.24	***
Error R x Y x CS	12	1.978	0.1648		
SA	4	92.576	23.144	76.14	***
Y x SA	4	0.501	0.1253	0.41	NS
CS x SA	12	1.384	0.1153	0.38	NS
Y x CS x SA	12	4.442	0.3702	1.22	NS
Error R x Y x CS x SA	64	19.453	0.304		
Total	119	412.025			
CV(R x Y)	0.57				
CV(R x Y x CS)	4.07				
CV(R x Y x CS x SA)	5.53				

Appendix 4ANOVA table for Soil moisture content at summer sowing at the depth 30-60 cm

Source	DF	SS	MS	F	P
R	2	4.202	2.101		
Y	1	157.323	157.323	2547.74	***
Error R x Y	2	0.123	0.062		
CS	3	35.513	11.838	291.29	***
Y x CS	3	24.166	8.055	198.21	***
Error R x Y x CS	12	0.488	0.041		
SA	4	94.801	23.7	112.86	***
Y x SA	4	1.543	0.386	1.84	NS
CS x SA	12	0.968	0.081	0.38	NS
Y x CS x SA	12	0.932	0.078	0.37	NS
Error R x Y x CS x SA	64	13.44	0.21		
Total	119	333.499			
CV(R x Y)	2.39				
CV(R x Y x CS)	1.94				
CV(R x Y x CS x SA)	4.41				

Appendix 5ANOVA table for Soil moisture content at summer sowing at the depth 30-90 cm

Source	DF	SS	MS	F	P
R	2	4.478	2.239		
Y	1	152.776	152.776	1691.25	***
Error R x Y	2	0.181	0.09		
CS	3	44.118	14.706	34.44	***
Y x CS	3	309.2	103.067	241.37	***
Error R x Y x CS	12	5.124	0.427		
SA	4	122.846	30.712	47.44	***
Y x SA	4	4.201	1.05	1.62	NS
CS x SA	12	8.143	0.679	1.05	NS
Y x CS x SA	12	36.419	3.035	4.69	***
Error R x Y x CS x SA	64	41.431	0.647		
Total	119	728.917			
CV(R x Y)	2.11				
CV(R x Y x CS)	4.59				
CV(R x Y x CS x SA)	5.65				

Appendix 6 ANOVA table of Summer post-harvest soil moisture at the depth of 0-30 cm

Source	DF	SS	MS	F	P
R	2	4.23	2.114		
Y	1	383.06	383.061	12128.6	***
Error R x Y	2	0.06	0.032		
CS	3	57.03	19.011	54.98	***
Y x CS	3	410.98	136.992	396.15	***
Error R x Y x CS	12	4.15	0.346		
SA	4	190.56	47.64	78.45	***
Y x SA	4	2.9	0.724	1.19	NS
CS x SA	12	2.96	0.247	0.41	NS
Y x CS x SA	12	9.49	0.79	1.3	NS
Error R x Y x CS x SA	64	38.87	0.607		
Total	119	1104.28			
CV(R x Y)	1.25				
CV(R x Y x CS)	4.12				
CV(R x Y x CS x SA)	5.46				

Appendix 7 ANOVA table of Summer post-harvest soil moisture at the depth of 30- 60 cm

Source	DF	SS	MS	F	P
R	2	6.115	3.0577		
Y	1	1.323	1.323	58.15	***
Error R x Y	2	0.045	0.0227		
CS	3	52.849	17.6162	329.45	***
Y x CS	3	35.854	11.9512	223.5	***
Error R x Y x CS	12	0.642	0.0535		
SA	4	139.009	34.7522	120.68	***
Y x SA	4	0.148	0.037	0.13	NS
CS x SA	12	1.231	0.1025	0.36	NS
Y x CS x SA	12	1.302	0.1085	0.38	NS
Error R x Y x CS x SA	64	18.431	0.288		
Total	119	256.948			
CV(R x Y)	1.2				
CV(R x Y x CS)	1.84				
CV(R x Y x CS x SA)	4.26				

Appendix 8 ANOVA table of Summer post-harvest soil moisture at the depth of 60- 90 cm

Source	DF	SS	MS	F	P
R	2	6.776	3.388		
Y	1	18.565	18.565	231.83	***
Error R x Y	2	0.16	0.08		
CS	3	54.954	18.318	31.42	***
Y x CS	3	451.646	150.549	258.19	***
Error R x Y x CS	12	6.997	0.583		
SA	4	182.964	45.741	49.46	***
Y x SA	4	6.142	1.536	1.66	NS
CS x SA	12	9.897	0.825	0.89	NS
Y x CS x SA	12	52.18	4.348	4.7	NS
Error R x Y x CS x SA	64	59.193	0.925		
Total	119	849.475			
CV(R x Y)	1.64				
CV(R x Y x CS)	4.41				
CV(R x Y x CS x SA)	5.56				

Appendix 9 ANOVA table for Soil moister contents at winter harvesting at the depth of 0-30 cm

Source	DF	SS	MS	F	P
R	2	5.781	2.891		
Y	1	122.816	122.816	5966.79	***
Error R x Y	2	0.041	0.021		
CS	3	78.049	26.016	8592.51	***
Y x CS	3	0.663	0.221	72.99	***
Error R x Y x CS	12	0.036	0.003		
SA	4	99.066	24.767	129.27	***
Y x SA	4	0.81	0.203	1.06	NS
CS x SA	12	0.55	0.046	0.24	NS
Y x CS x SA	12	0.02	0.002	0.01	NS
Error R x Y x CS x SA	64	12.261	0.192		
Total	119	320.095			
CV(R x Y)	0.9				
CV(R x Y x CS)	0.34				
CV(R x Y x CS x SA)	2.73				

Appendix 10 ANOVA table for Soil moister contents at winter harvesting at the depth of 30-60 cm

Source	DF	SS	MS	F	P
R	2	7.071	3.536		
Y	1	149.187	149.187	5474.75	***
Error R x Y	2	0.054	0.027		
CS	3	95.114	31.705	4356.37	***
Y x CS	3	0.718	0.239	32.87	***
Error R x Y x CS	12	0.087	0.007		
SA	4	122.575	30.644	128.46	***
Y x SA	4	1.056	0.264	1.11	NS
CS x SA	12	0.763	0.064	0.27	NS
Y x CS x SA	12	0.019	0.002	0.01	NS
Error R x Y x CS x SA	64	15.267	0.239		
Total	119	391.912			
CV(R x Y)	0.96				
CV(R x Y x CS)	0.5				
CV(R x Y x CS x SA)	2.85				

Appendix 11 ANOVA table for Soil moister contents at winter harvesting at the depth of 60-90 cm

Source	DF	SS	MS	F	P
R	2	183.15	91.575		
Y	1	119.6	119.6	159.03	***
Error R x Y	2	1.504	0.752		
CS	3	75.897	25.299	316.57	***
Y x CS	3	0.6	0.2	2.5	***
Error R x Y x CS	12	0.959	0.08		
SA	4	110.604	27.651	44.77	***
Y x SA	4	0.901	0.225	0.36	NS
CS x SA	12	0.586	0.049	0.08	NS
Y x CS x SA	12	0.019	0.002	0	NS
Error R x Y x CS x SA	64	39.527	0.618		
Total	119	533.347			
CV(R x Y)	5.46				
CV(R x Y x CS)	1.78				
CV(R x Y x CS x SA)	4.95				

Appendix 12 ANOVA table for Soil Bulk Density

Source	DF	SS	MS	F	P
R	2	0.00487	0.00244		
Y	1	0.51614	0.51614	758.1	***
Error R x Y	2	0.00136	0.00068		
CS	3	0.09736	0.03245	319.22	***
Y x CS	3	0.02488	0.00829	81.58	***
Error R x Y x CS	12	0.00122	0.0001		
SA	4	0.03079	0.0077	58.1	***
Y x SA	4	0.00814	0.00203	15.36	***
CS x SA	12	0.34751	0.02896	218.56	***
Y x CS x SA	12	0.02172	0.00181	13.66	***
Error R x Y x CS x SA	64	0.00848	0.00013		
Total	119	1.06248			
CV(R x Y)	1.83				
CV(R x Y x CS)	0.71				
CV(R x Y x CS x SA)	0.81				

Appendix 13ANOVA table for Summer water use efficiency

Source	DF	SS	MS	F	P
R	2	2.056	1.0281		
Y	1	0.077	0.077	10.64	0.0825
Error R x Y	2	0.014	0.0072		
CS	3	112.386	37.4619	259.53	0
Y x CS	3	0.659	0.2197	1.52	0.2592
Error R x Y x CS	12	1.732	0.1443		
SA	4	0.193	0.0482	4.19	0.0045
Y x SA	4	0.026	0.0064	0.56	0.6949
CS x SA	12	0.191	0.0159	1.38	0.1978
Y x CS x SA	12	0.133	0.0111	0.96	0.4917
Error R x Y x CS x SA	64	0.736	0.0115		
Total	119	118.203			
CV(R x Y)	6.38				
CV(R x Y x CS)	28.48				
CV(R x Y x CS x SA)	8.04				

Appendix 14 ANOVA table for Winter Water Use Efficiency

Source	DF	SS	MS	F	P
R	2	144.596	72.298		
Y	1	223.433	223.433	1417.71	***
Error R x Y	2	0.315	0.158		
CS	3	15.819	5.273	8.1	***
Y x CS	3	11.692	3.897	5.99	***
Error R x Y x CS	12	7.812	0.651		
SA	4	5.843	1.461	5.49	***
Y x SA	4	2.788	0.697	2.62	***
CS x SA	12	85.184	7.099	26.69	***
Y x CS x SA	12	13.367	1.114	4.19	***
Error R x Y x CS x SA	64	17.019	0.266		
Total	119	527.867			
CV(R x Y)	3				
CV(R x Y x CS)	6.11				
CV(R x Y x CS x SA)	3.9				

Appendix 15 ANOVA table for Mungbean seed yield

Source	DF	SS	MS	F	P
R	2	927851	463926		
Y	1	165375	165375	83.21	***
Error R x Y	2	3975	1988		
CS	1	766140	766140	152.35	***
Y x CS	1	2	2	0	NS
Error R x Y x CS	4	20115	5029		
SA	4	57330	14332	106.86	***
Y x SA	4	3235	809	6.03	***
CS x SA	4	9889	2472	18.43	***
Y x CS x SA	4	942	235	1.76	NS
Error R x Y x CS x SA	32	4292	134		
Total	59	1959146			
CV(R x Y)	4.57				
CV(R x Y x CS)	7.27				
CV(R x Y x CS x SA)	1.19				

Appendix 16 ANOVA table for Mungbean plant height

Source	DF	SS	MS	F	P
R	2	183.07	91.5352		
Y	1	15.1441	15.1441	757.54	***
Error R x Y	2	0.03998	0.01999		
CS	1	0.64273	0.64273	9.20E+28	***
Y x CS	1	5.12E-30	5.12E-30	0.73	NS
Error R x Y x CS	4	2.80E-29	6.99E-30		
SA	4	363.467	90.8668	3029.49	***
Y x SA	4	0.07938	0.01985	0.66	
CS x SA	4	3.25E-28	8.12E-29	0	NS
Y x CS x SA	4	6.10E-29	1.52E-29	0	NS
Error R x Y x CS x SA	32	0.95981	0.02999		NS
Total	59	563.404			
CV(R x Y)	0.32				
CV(R x Y x CS)	0				
CV(R x Y x CS x SA)	0.4				

Appendix 17 ANOVA table for Mungbean number of plants per square meter

Source	DF	SS	MS	F	P
R	2	4.869	2.4345		
Y	1	0.6407	0.64067	295.69	***
Error R x Y	2	0.0043	0.00217		
CS	1	0.0427	0.04267	11.64	***
Y x CS	1	0.0007	0.00067	0.18	NS
Error R x Y x CS	4	0.0147	0.00367		
SA	4	14.239	3.55975	135.83	***
Y x SA	4	0.0277	0.00692	0.26	NS
CS x SA	4	0.0357	0.00892	0.34	NS
Y x CS x SA	4	0.011	0.00275	0.1	NS
Error R x Y x CS x SA	32	0.8387	0.02621		
Total	59	20.724			
CV(R x Y)	0.71				
CV(R x Y x CS)	0.93				
CV(R x Y x CS x SA)	2.48				

Appendix 18 ANOVA table for Mungbean number of branches per square meter

Source	DF	SS	MS	F	P
R	2	1298.58	649.29		
Y	1	281.8	281.8	179.76	0.0055
Error R x Y	2	3.14	1.57		
CS	1	2038.05	2038.05	183.08	0.0002
Y x CS	1	0.14	0.14	0.01	0.9169
Error R x Y x CS	4	44.53	11.13		
SA	4	789.24	197.31	39.19	0
Y x SA	4	7.73	1.93	0.38	0.8184
CS x SA	4	23.99	6	1.19	0.3336
Y x CS x SA	4	7.08	1.77	0.35	0.841
Error R x Y x CS x SA	32	161.12	5.03		
Total	59	4655.39			
CV(R x Y)	2.44				
CV(R x Y x CS)	6.51				
CV(R x Y x CS x SA)	4.38				

Appendix 19 ANOVA table for Mungbean number of pods

Source	DF	SS	MS	F	P
R	2	34.679	17.3395		
Y	1	4.439	4.439	801.27	0.0012
Error R x Y	2	0.011	0.0055		
CS	1	0.204	0.2042	2.47	0.1912
Y x CS	1	0.011	0.0107	0.13	0.7376
Error R x Y x CS	4	0.331	0.0827		
SA	4	102.503	25.6258	136.85	0
Y x SA	4	0.094	0.0235	0.13	0.9722
CS x SA	4	0.291	0.0728	0.39	0.8152
Y x CS x SA	4	0.078	0.0194	0.1	0.9804
Error R x Y x CS x SA	32	5.992	0.1873		
Total	59	148.633			
CV(R x Y)	0.42				
CV(R x Y x CS)	1.63				
CV(R x Y x CS x SA)	2.45				

Appendix 20ANOVA table for Mungbean thousand grains weight

Source	DF	SS	MS	F	P
R	2	89.7985	44.8992		
Y	1	7.42017	7.42017	753.57	***
Error R x Y	2	0.01969	0.00985		
CS	1	0.30817	0.30817	46225	***
Y x CS	1	2.67E-05	2.67E-05	4	NS
Error R x Y x CS	4	2.67E-05	6.67E-06		
SA	4	178.175	44.5437	3024.02	***
Y x SA	4	0.03922	0.0098	0.67	NS
CS x SA	4	5.00E-05	1.25E-05	0	NS
Y x CS x SA	4	2.33E-05	5.83E-06	0	NS
Error R x Y x CS x SA	32	0.47136	0.01473		
Total	59	276.232			
CV(R x Y)	0.32				
CV(R x Y x CS)	0.01				
CV(R x Y x CS x SA)	0.4				

Appendix 21ANOVA table for Mungbean biological yield

Source	DF	SS	MS	F	P
R	2	15360000	7682693		
Y	1	6070620	6070620	61.01	***
Error R x Y	2	198989	99495		
CS	1	3364928	3364928	3.16	NS
Y x CS	1	2419.35	2419	0	NS
Error R x Y x CS	4	4257108	1064277		
SA	4	3071577	767894	156.83	***
Y x SA	4	316163	79041	16.14	***
CS x SA	4	71467.1	17867	3.65	***
Y x CS x SA	4	5927.07	1482	0.3	NS
Error R x Y x CS x SA	32	156681	4896		
Total	59	32880000			
CV(R x Y)	10.24				
CV(R x Y x CS)	33.48				
CV(R x Y x CS x SA)	2.27				

Appendix 22ANOVA table for Mungbean harvest index

Source	DF	SS	MS	F	P
R	2	85.174	42.587		
Y	1	151.114	151.114	1461.24	***
Error R x Y	2	0.207	0.103		
CS	1	67.204	67.204	0.78	NS
Y x CS	1	0.164	0.164	0	NS
Error R x Y x CS	4	344.801	86.2		
SA	4	107.484	26.871	932.92	***
Y x SA	4	26.839	6.71	232.95	***
CS x SA	4	0.116	0.029	1.01	NS
Y x CS x SA	4	0.029	0.007	0.26	NS
Error R x Y x CS x SA	32	0.922	0.029		
Total	59	784.056			
CV(R x Y)	1				
CV(R x Y x CS)	28.77				
CV(R x Y x CS x SA)	0.53				

Appendix 23 ANOVA table for Sorghum No of plants /m^2

Source	DF	SS	MS	F	P
R	2	4.869	2.4345		
Y	1	0.6407	0.64067	295.69	***
Error R x Y	2	0.0043	0.00217		
CS	1	0.0427	0.04267	11.64	***
Y x CS	1	0.0007	0.00067	0.18	NS
Error R x Y x CS	4	0.0147	0.00367		
SA	4	14.239	3.55975	135.83	***
Y x SA	4	0.0277	0.00692	0.26	NS
CS x SA	4	0.0357	0.00892	0.34	NS
Y x CS x SA	4	0.011	0.00275	0.1	NS
Error R x Y x CS x SA	32	0.8387	0.02621		
Total	59	20.724			
CV(R x Y)	0.71				
CV(R x Y x CS)	0.93				
CV(R x Y x CS x SA)	2.48				

Appendix 24 ANOVA table for Sorghum plant height

Source	DF	SS	MS	F	P
R	2	3392.2	1696.08		
Y	1	5411.2	5411.2	725.3	***
Error R x Y	2	14.9	7.46		
CS	1	2452.5	2452.48	1699.18	***
Y x CS	1	15	15	10.39	***
Error R x Y x CS	4	5.8	1.44		
SA	4	2283.3	570.84	1245.35	***
Y x SA	4	664.8	166.2	362.58	***
CS x SA	4	10.5	2.61	5.7	***
Y x CS x SA	4	1.8	0.44	0.96	
Error R x Y x CS x SA	32	14.7	0.46		
Total	59	14266.5			
CV(R x Y)	2.25				
CV(R x Y x CS)	0.99				
CV(R x Y x CS x SA)	0.56				

Appendix 25 ANOVA table for Sorghum panicle length

Source	DF	SS	MS	F	P
R	2	44.971	22.4855		
Y	1	5.46	5.4602	668.59	***
Error R x Y	2	0.016	0.0082		
CS	1	31.537	31.5375	1034.02	***
Y x CS	1	0.013	0.0135	0.44	NS
Error R x Y x CS	4	0.122	0.0305		
SA	4	56.449	14.1123	2016.05	***
Y x SA	4	4.387	1.0968	156.69	***
CS x SA	4	0.157	0.0392	5.6	***
Y x CS x SA	4	0.011	0.0027	0.38	NS
Error R x Y x CS x SA	32	0.224	0.007		
Total	59	143.348			
CV(R x Y)	0.65				
CV(R x Y x CS)	1.27				
CV(R x Y x CS x SA)	0.61				

Appendix 26ANOVA table for Sorghum thousand grains weight

Source	DF	SS	MS	F	P
R	2	142.876	71.438		
Y	1	16.896	16.896	507.25	***
Error R x Y	2	0.067	0.033		
CS	1	100.379	100.379	1014.03	***
Y x CS	1	0.047	0.047	0.47	NS
Error R x Y x CS	4	0.396	0.099		
SA	4	181.743	45.436	1883.09	***
Y x SA	4	13.541	3.385	140.31	***
CS x SA	4	0.503	0.126	5.22	***
Y x CS x SA	4	0.038	0.009	0.39	NS
Error R x Y x CS x SA	32	0.772	0.024		
Total	59	457.258			
CV(R x Y)	0.74				
CV(R x Y x CS)	1.28				
CV(R x Y x CS x SA)	0.63				

Appendix 27ANOVA table for Sorghum grain yield

Source	DF	SS	MS	F	P
R	2	569569	284784		
Y	1	1084	1084	40.74	**
Error R x Y	2	53	27		
CS	1	473304	473304	144.35	***
Y x CS	1	1392	1392	0.42	
Error R x Y x CS	4	13115	3279		NS
SA	4	29745	7436	90.13	***
Y x SA	4	1847	462	5.6	***
CS x SA	4	6585	1646	19.95	***
Y x CS x SA	4	590	148	1.79	NS
Error R x Y x CS x SA	32	2640	83		
Total	59	1099925			
CV(R x Y)	0.67				
CV(R x Y x CS)	7.46				
CV(R x Y x CS x SA)	1.18				

Appendix 28ANOVA table for Sorghum biological yield

Source	DF	SS	MS	F	P
R	2	1.07E+07	5370063		
Y	1	771800	771800	43.89	***
Error R x Y	2	35172	17586		
CS	1	2366120	2366120	3.18	NS
Y x CS	1	1717.35	1717	0	NS
Error R x Y x CS	4	2977867	744467		
SA	4	1955650	488912	155.38	***
Y x SA	4	139563	34891	11.09	***
CS x SA	4	54892.5	13723	4.36	***
Y x CS x SA	4	3468.23	867	0.28	NS
Error R x Y x CS x SA	32	100690	3147		
Total	59	1.92E+07			
CV(R x Y)	4.3				
CV(R x Y x CS)	27.98				
CV(R x Y x CS x SA)	1.82				

Appendix 29 ANOVA table for Sorghum harvest index

Source	DF	SS	MS	F	P
R	2	4.194	2.0971		
Y	1	65.229	65.2292	16527.7	***
Error R x Y	2	0.008	0.0039		
CS	1	88.963	88.9627	2.9	NS
Y x CS	1	0.493	0.4932	0.02	NS
Error R x Y x CS	4	122.558	30.6396		
SA	4	31.83	7.9574	798.97	***
Y x SA	4	11.859	2.9649	297.69	***
CS x SA	4	1.06	0.265	26.61	***
Y x CS x SA	4	0.143	0.0358	3.6	NS
Error R x Y x CS x SA	32	0.319	0.01		
Total	59	326.657			
CV(R x Y)	0.25				
CV(R x Y x CS)	22.12				
CV(R x Y x CS x SA)	0.4				

Appendix 30 ANOVA table for wheat grain yield

Source	DF	SS	MS	F	P
R	2	5139127	2569563		
Y	1	3859422	3859422	31.78	**
Error R x Y	2	242860	121430		
CS	3	3759.5	1253	0.31	NS
Y x CS	3	33713.1	11238	2.82	NS
Error R x Y x CS	12	47833.4	3986		
SA	4	4153765	1038441	90.37	***
Y x SA	4	460676	115169	10.02	***
CS x SA	12	133872	11156	0.97	NS
Y x CS x SA	12	73573	6131	0.53	NS
Error R x Y x CS x SA	64	735460	11492		
Total	119	1.49E+07			
CV(R x Y)	14.42				
CV(R x Y x CS)	2.61				
CV(R x Y x CS x SA)	4.44				

Appendix 31 ANOVA table for wheat biological yield

Source	DF	SS	MS	F	P
R	2	4.16E+07	2.08E+07		
Y	1	3.19E+07	3.19E+07	33.1	***
Error R x Y	2	1927837	963919		
CS	3	3366518	1122173	29.05	***
Y x CS	3	163173	54391.1	1.41	NS
Error R x Y x CS	12	463549	38629.1		
SA	4	7.07E+07	1.77E+07	206.02	***
Y x SA	4	2470934	617733	7.2	***
CS x SA	12	1411581	117632	1.37	NS
Y x CS x SA	12	503986	41998.9	0.49	NS
Error R x Y x CS x SA	64	5489859	85779		
Total	119	1.60E+08			
CV(R x Y)	15.2				
CV(R x Y x CS)	3.04				
CV(R x Y x CS x SA)	4.54				

Appendix 32 ANOVA table for wheat harvest index

Source	DF	SS	MS	F	P
R	2	5.267	2.6333		
Y	1	8.008	8.0083	240.25	***
Error R x Y	2	0.067	0.0333		
CS	3	106.025	35.3417	96.39	***
Y x CS	3	0.225	0.075	0.2	NS
Error R x Y x CS	12	4.4	0.3667		
SA	4	336.717	0.1958	396.14	***
Y x SA	4	0.783	0.1958	0.92	NS
CS x SA	12	38.017	3.1681	14.91	***
Y x CS x SA	12	2.483	0.2069	0.97	NS
Error R x Y x CS x SA	64	13.6	0.2125		
Total	119	515.592			
CV(R x Y)	0.49				
CV(R x Y x CS)	1.61				
CV(R x Y x CS x SA)	1.22				

Appendix 33 ANOVA table for Wheat Number of tillers

Source	DF	SS	MS	F	P
R	2	28551	14275.30		
Y	1	20021	20020.80	36.06	**
Error R x Y	2	1110	555.20		
CS	3	2139	713.20	82.31	***
Y x CS	3	20	6.80	0.79	NS
Error R x Y x CS	12	104	8.70		
SA	4	45606	11401.40	268.15	***
Y x SA	4	1122	280.50	6.6	***
CS x SA	12	933	77.70	1.83	*
Y x CS x SA	12	203	16.90	0.4	NS
Error R x Y x CS x SA	64	2721	42.50		
Total	119	102530			
CV(R x Y)	14.52				
CV(R x Y x CS)	1.81				
CV(R x Y x CS x SA)	4.02				

Appendix 34ANOVA table for Wheat Grains per spike

Source	DF	SS	MS	F	P
R	2	1795.85	897.92		
Y	1	1320.03	1320.03	40.17	**
Error R x Y	2	65.72	32.86		
CS	3	135.63	45.21	91.95	***
Y x CS	3	0.97	0.32	0.66	NS
Error R x Y x CS	12	5.9	0.49		
SA	4	2873.55	718.39	271.73	***
Y x SA	4	72.72	18.18	6.88	***
CS x SA	12	57.78	4.82	1.82	*
Y x CS x SA	12	11.95	1	0.38	NS
Error R x Y x CS x SA	64	169.2	2.64		
Total	119	6509.3			
CV(R x Y)	14.03				
CV(R x Y x CS)	1.72				
CV(R x Y x CS x SA)	3.98				

Appendix 35ANOVA table for Wheat Spikelets per spike

Source	**DF**	**SS**	**MS**	**F**	**P**
R	2	218.867	109.433		
Y	1	147.408	147.408	39.48	**
Error R x Y	2	7.467	3.733		
CS	3	19.892	6.631	62.82	***
Y x CS	3	0.492	0.164	1.55	NS
Error R x Y x CS	12	1.267	0.106		
SA	4	351.883	87.971	189.35	***
Y x SA	4	4.05	1.012	2.18	***
CS x SA	12	7.65	0.637	1.37	NS
Y x CS x SA	12	1.883	0.157	0.34	NS
Error R x Y x CS x SA	64	29.733	0.465		
Total	119	790.592			
CV(R x Y)	13.74				
CV(R x Y x CS)	2.31				
CV(R x Y x CS x SA)	4.85				

Appendix 36 Thousand grains weight (g)

SoV	**DF**	**SS**	**MS**	**F**	**P**
R	2	2162.62	1081.31		
Y	1	1519.41	1519.41	40.08	**
Error R x Y	2	75.82	37.91		
CS	3	164.49	54.83	91.81	***
Y x CS	3	2.09	0.7	1.17	NS
Error R x Y x CS	12	7.17	0.6		
SA	4	3538.13	884.53	269.91	***
Y x SA	4	96.47	24.12	7.36	***
CS x SA	12	77.47	6.46	1.97	**
Y x CS x SA	12	16.2	1.35	0.41	NS
Error R x Y x CS x SA	64	209.73	3.28		
Total	119	7869.59			
CV(R x Y)	13.65				
CV(R x Y x CS)	1.71				
CV(R x Y x CS x SA)	4.01				

Appendix 37 ANOVA table for Mungbean Crop Growth Rate at 30 DAS

Source	DF	SS	MS	F	P
R	2	2.1169	1.05845		
Y	1	2.4	2.4	103.09	***
Error R x Y	2	0.0466	0.02328		
CS	1	3.1008	3.10083	173.65	***
Y x CS	1	0.2561	0.25611	14.34	**
Error R x Y x CS	4	0.0714	0.01786		
SA	4	1.4925	0.37313	43.1	***
Y x SA	4	0.0494	0.01234	1.43	NS
CS x SA	4	3.799	0.94974	109.7	***
Y x CS x SA	4	0.0702	0.01755	2.03	NS
Error R x Y x CS x SA	32	0.2771	0.00866		
Total	59	13.6799			
CV(R x Y)	6.61				
CV(R x Y x CS)	5.79				
CV(R x Y x CS x SA)	4.03				

Appendix 38 ANOVA table for Mungbean Crop Growth Rate at 60 DAS

Source	DF	SS	MS	F	P
R	2	47.319	23.6593		
Y	1	55.008	55.0084	67.06	***
Error R x Y	2	1.64	0.8202		
CS	1	71.177	71.177	130.89	***
Y x CS	1	5.322	5.3223	9.79	**
Error R x Y x CS	4	2.175	0.5438		
SA	4	35.908	8.977	46.17	***
Y x SA	4	1.281	0.3202	1.65	NS
CS x SA	4	87.577	21.8941	112.6	***
Y x CS x SA	4	1.352	0.338	1.74	NS
Error R x Y x CS x SA	32	6.222	0.1944		
Total	59	314.981			
CV(R x Y)	8.03				
CV(R x Y x CS)	6.54				
CV(R x Y x CS x SA)	3.91				

Appendix 39 ANOVA table for Mungbean Crop Growth Rate at 90 DAS

Source	DF	SS	MS	F	P
R	2	4.0481	2.02404		
Y	1	4.6705	4.67046	66.05	***
Error R x Y	2	0.1414	0.07071		
CS	1	6.0293	6.02934	130.34	***
Y x CS	1	0.4507	0.45067	9.74	**
Error R x Y x CS	4	0.185	0.04626		
SA	4	3.0519	0.76298	46.46	***
Y x SA	4	0.1081	0.02702	1.65	NS
CS x SA	4	7.4591	1.86478	113.55	***
Y x CS x SA	4	0.1143	0.02858	1.74	NS
Error R x Y x CS x SA	32	0.5255	0.01642		
Total	59	26.784			
CV(R x Y)	8.09				
CV(R x Y x CS)	6.54				
CV(R x Y x CS x SA)	3.9				

Appendix 40 ANOVA table for Sorghum Crop Growth Rate at 30 DAS

Source	DF	SS	MS	F	P
R	2	6.208	3.10398		
Y	1	7.0933	7.09328	102.27	***
Error R x Y	2	0.1387	0.06936		
CS	1	9.0715	9.07148	174.23	***
Y x CS	1	0.7549	0.75488	14.5	**
Error R x Y x CS	4	0.2083	0.05207		
SA	4	4.3965	1.09912	43.14	***
Y x SA	4	0.1334	0.03334	1.31	NS
CS x SA	4	11.1964	2.7991	109.87	***
Y x CS x SA	4	0.195	0.04874	1.91	NS
Error R x Y x CS x SA	32	0.8152	0.02548		
Total	59	40.2111			
CV(R x Y)	6.67				
CV(R x Y x CS)	5.78				
CV(R x Y x CS x SA)	4.04				

Appendix 41 ANOVA table for Sorghum Crop Growth Rate at 60 DAS

Source	DF	SS	MS	F	P
R	2	6.208	3.10398		
Y	1	7.0933	7.09328	102.27	***
Error R x Y	2	0.1387	0.06936		
CS	1	9.0715	9.07148	174.23	***
Y x CS	1	0.7549	0.75488	14.5	**
Error R x Y x CS	4	0.2083	0.05207		
SA	4	4.3965	1.09912	43.14	***
Y x SA	4	0.1334	0.03334	1.31	NS
CS x SA	4	11.1964	2.7991	109.87	***
Y x CS x SA	4	0.195	0.04874	1.91	NS
Error R x Y x CS x SA	32	0.8152	0.02548		
Total	59	40.2111			
CV(R x Y)	6.67				
CV(R x Y x CS)	5.78				
CV(R x Y x CS x SA)	4.04				

Appendix 42 ANOVA table for Sorghum Crop Growth Rate at 90 DAS

Source	DF	SS	MS	F	P
R	2	11.203	5.6015		
Y	1	13.02	13.02	66.36	***
Error R x Y	2	0.3924	0.1962		
CS	1	16.7799	16.7799	128.2	***
Y x CS	1	1.2644	1.2644	9.66	**
Error R x Y x CS	4	0.5235	0.1309		
SA	4	8.501	2.1252	45.68	***
Y x SA	4	0.3049	0.0762	1.64	NS
CS x SA	4	20.723	5.1808	111.35	***
Y x CS x SA	4	0.3182	0.0795	1.71	NS
Error R x Y x CS x SA	32	1.4889	0.0465		
Total	59	74.5193			
CV(R x Y)	8.08				
CV(R x Y x CS)	6.6				
CV(R x Y x CS x SA)	3.94				

Appendix 43 ANOVA table for Wheat crop growth rate at Z-13

Source	DF	SS	MS	F	P
R	2	0.06058	0.03029		
Y	1	0.04681	0.04681	33.02	**
Error R x Y	2	0.00284	0.00142		
CS	3	0.03872	0.01291	34.91	***
Y x CS	3	0.00266	0.00089	2.4	NS
Error R x Y x CS	12	0.00444	0.00037		
SA	4	0.0078	0.00195	23.04	***
Y x SA	4	0.00045	0.00011	1.32	NS
CS x SA	12	0.0673	0.00561	66.3	***
Y x CS x SA	12	0.00137	0.00011	1.35	NS
Error R x Y x CS x SA	64	0.00541	0.00008		
Total	119	0.23836			
CV(R x Y)	15.28				
CV(R x Y x CS)	7.8				
CV(R x Y x CS x SA)	3.73				

Appendix 44 ANOVA table for Wheat crop growth rate at Z-47

Source	DF	SS	MS	F	P
R	2	7.001	3.50051		
Y	1	5.3848	5.3848	33	**
Error R x Y	2	0.3263	0.16316		
CS	3	4.2965	1.43216	36.91	***
Y x CS	3	0.3155	0.10518	2.71	NS
Error R x Y x CS	12	0.4657	0.03881		
SA	4	0.9052	0.2263	26.24	***
Y x SA	4	0.0523	0.01309	1.52	NS
CS x SA	12	7.5297	0.62748	72.75	***
Y x CS x SA	12	0.159	0.01325	1.54	NS
Error R x Y x CS x SA	64	0.552	0.00863		
Total	119	26.9881			
CV(R x Y)	15.24				
CV(R x Y x CS)	7.43				
CV(R x Y x CS x SA)	3.5				

Appendix 45 ANOVA table for Wheat crop growth rate at Z-60

Source	DF	SS	MS	F	P
R	2	251.091	125.546		
Y	1	192.761	192.761	33.08	**
Error R x Y	2	11.656	5.828		
CS	3	153.358	51.119	37.7	***
Y x CS	3	11.333	3.778	2.79	NS
Error R x Y x CS	12	16.272	1.356		
SA	4	32.361	8.09	26.31	***
Y x SA	4	1.869	0.467	1.52	NS
CS x SA	12	270.092	22.508	73.2	***
Y x CS x SA	12	5.761	0.48	1.56	NS
Error R x Y x CS x SA	64	19.68	0.307		
Total	119	966.234			
CV(R x Y)	15.21				
CV(R x Y x CS)	7.34				
CV(R x Y x CS x SA)	3.49				

Appendix 46 ANOVA table for Wheat crop growth rate at Z-85

Source	DF	SS	MS	F	P
R	2	10.3969	5.19845		
Y	1	7.9877	7.98768	33.23	**
Error R x Y	2	0.4807	0.24035		
CS	3	6.3371	2.11236	37.77	***
Y x CS	3	0.4742	0.15805	2.83	NS
Error R x Y x CS	12	0.6711	0.05592		
SA	4	1.3398	0.33495	26.01	***
Y x SA	4	0.0769	0.01923	1.49	NS
CS x SA	12	11.1919	0.93266	72.42	***
Y x CS x SA	12	0.2411	0.02009	1.56	NS
Error R x Y x CS x SA	64	0.8242	0.01288		
Total	119	40.0216			
CV(R x Y)	15.18				
CV(R x Y x CS)	7.32				
CV(R x Y x CS x SA)	3.51				

Appendix 47 ANOVA table for Wheat leaf area index

Source	DF	SS	MS	F	P
R	2	29.284	14.6422		
Y	1	22.438	22.4381	33.12	**
Error R x Y	2	1.355	0.6775		
CS	3	17.891	5.9638	37.73	***
Y x CS	3	1.315	0.4383	2.77	NS
Error R x Y x CS	12	1.897	0.1581		
SA	4	3.773	0.9432	26.44	***
Y x SA	4	0.213	0.0532	1.49	NS
CS x SA	12	31.428	2.619	73.43	***
Y x CS x SA	12	0.671	0.056	1.57	NS
Error R x Y x CS x SA	64	2.283	0.0357		
Total	119	112.548			
CV(R x Y)	15.19				
CV(R x Y x CS)	7.34				
CV(R x Y x CS x SA)	3.49				

Appendix 48 ANOVA table for Wheat leaf area duration

Source	DF	SS	MS	F	P
R	2	6278.6	3139.3		
Y	1	4816.4	4816.37	33.09	**
Error R x Y	2	291.1	145.55		
CS	3	3832.1	1277.38	37.69	***
Y x CS	3	283.3	94.42	2.79	NS
Error R x Y x CS	12	406.7	33.89		
SA	4	811.2	202.79	26.38	***
Y x SA	4	47	11.74	1.53	NS
CS x SA	12	6748.9	562.41	73.15	***
Y x CS x SA	12	143.7	11.97	1.56	NS
Error R x Y x CS x SA	64	492	7.69		
Total	119	24151			
CV(R x Y)	15.2				
CV(R x Y x CS)	7.34				
CV(R x Y x CS x SA)	3.49				

Appendix 49 ANOVA table for Wheat net assimilation rate

Source	DF	SS	MS	F	P
R	2	8.3095	4.15477		
Y	1	6.3664	6.36641	33.29	**
Error R x Y	2	0.3824	0.19122		
CS	3	5.0798	1.69326	37.82	***
Y x CS	3	0.3768	0.12559	2.81	NS
Error R x Y x CS	12	0.5372	0.04477		
SA	4	1.0701	0.26752	26.11	***
Y x SA	4	0.0625	0.01562	1.52	NS
CS x SA	12	8.913	0.74275	72.48	***
Y x CS x SA	12	0.1862	0.01551	1.51	NS
Error R x Y x CS x SA	64	0.6558	0.01025		
Total	119	31.9397			
CV(R x Y)	15.16				
CV(R x Y x CS)	7.34				
CV(R x Y x CS x SA)	3.51				

Appendix 50 ANOVA table for Sorghum photosynthetic rate

Source	DF	SS	MS	F	P
R	2	2.742	1.3708		
Y	1	95.988	95.9882	24.25	**
Error R x Y	2	7.916	3.958		
CS	1	0.203	0.203	0.53	NS
Y x CS	1	0.011	0.0115	0.03	NS
Error R x Y x CS	4	1.526	0.3814		
SA	4	56.123	14.0308	11.12	***
Y x SA	4	0.875	0.2187	0.17	NS
CS x SA	4	36.541	9.1353	7.24	***
Y x CS x SA	4	1.525	0.3813	0.3	NS
Error R x Y x CS x SA	32	40.374	1.2617		
Total	59	243.824			
CV(R x Y)	7.48				
CV(R x Y x CS)	2.32				
CV(R x Y x CS x SA)	4.22				

Appendix 51ANOVA table for Sorghum transpiration rate

Source	DF	SS	MS	F	P
R	2	59.9407	29.9703		
Y	1	0.20306	0.20306	118.23	**
Error R x Y	2	0.00343	0.00172		
CS	1	0.08496	0.08496	236.43	***
Y x CS	1	1.37E-05	1.37E-05	0.04	NS
Error R x Y x CS	4	0.00144	3.59E-04		
SA	4	5.61943	1.40486	373.92	***
Y x SA	4	0.00602	0.0015	0.4	NS
CS x SA	4	1.48071	0.37018	98.53	***
Y x CS x SA	4	0.0012	3.00E-04	0.08	NS
Error R x Y x CS x SA	32	0.12023	0.00376		
Total	59	67.4612			
CV(R x Y)	0.54				
CV(R x Y x CS)	0.25				
CV(R x Y x CS x SA)	1.8				

Appendix 52 ANOVA table for Sorghum stomatal conductance

Source	DF	SS	MS	F	P
R	2	0.52684	0.26342		
Y	1	0.21963	0.21963	118.23	**
Error R x Y	2	0.00372	0.00186		
CS	1	0.00103	0.00103	138.4	***
Y x CS	1	0.00073	0.00073	98.06	NS
Error R x Y x CS	4	0.00003	0.00001		
SA	4	0.37573	0.09393	435.95	***
Y x SA	4	0.02445	0.00611	28.37	NS
CS x SA	4	0.00605	0.00151	7.02	***
Y x CS x SA	4	0.00137	0.00034	1.59	NS
Error R x Y x CS x SA	32	0.00689	0.00022		
Total	59	1.16648			
CV(R x Y)	5.98				
CV(R x Y x CS)	0.38				
CV(R x Y x CS x SA)	2.04				

Appendix 53 ANOVA table for Mungbean photosynthetic rate

Source	DF	SS	MS	F	P
R	2	6.17	3.086		
Y	1	101.92	101.921	22.33	**
Error R x Y	2	9.13	4.565		
CS	1	504.6	504.6	109.96	***
Y x CS	1	11.18	11.18	2.44	NS
Error R x Y x CS	4	18.36	4.589		
SA	4	251.55	62.888	12.91	***
Y x SA	4	16.38	4.096	0.84	NS
CS x SA	4	594.39	148.597	30.5	***
Y x CS x SA	4	4.89	1.223	0.25	NS
Error R x Y x CS x SA	32	155.89	4.872		
Total	59	1674.46			
CV(R x Y)	7.42				
CV(R x Y x CS)	7.44				
CV(R x Y x CS x SA)	7.66				

Appendix 54 ANOVA table for Mungbean transpiration rate

Source	DF	SS	MS	F	P
R	2	54.2054	27.1027		
Y	1	0.12287	0.12287	118.23	**
Error R x Y	2	0.00208	0.00104		
CS	1	0.23929	0.23929	236.45	***
Y x CS	1	1.51E-05	1.51E-05	0.01	NS
Error R x Y x CS	4	0.00405	0.00101		
SA	4	8.16683	2.04171	470.91	***
Y x SA	4	0.00379	9.49E-04	0.22	NS
CS x SA	4	0.03011	0.00753	1.74	***
Y x CS x SA	4	0.00115	2.87E-04	0.07	NS
Error R x Y x CS x SA	32	0.13874	0.00434		
Total	59	62.9143			
CV(R x Y)	0.44				
CV(R x Y x CS)	0.44				
CV(R x Y x CS x SA)	0.9				

Appendix 55 ANOVA table for Mungbean stomatal conductance

Source	DF	SS	MS	F	P
R	2	0.58201	0.29101		
Y	1	0.1985	0.1985	118.23	**
Error R x Y	2	0.00336	0.00168		
CS	1	0.00334	0.00334	167.14	***
Y x CS	1	0.00138	0.00138	69.32	NS
Error R x Y x CS	4	0.00008	0.00002		
SA	4	0.55741	0.13935	457.28	***
Y x SA	4	0.01332	0.00333	10.93	NS
CS x SA	4	0.00363	0.00091	2.98	***
Y x CS x SA	4	0.00213	0.00053	1.75	NS
Error R x Y x CS x SA	32	0.00975	0.0003		
Total	59	1.37492			
CV(R x Y)	5.41				
CV(R x Y x CS)	0.59				
CV(R x Y x CS x SA)	2.31				

Appendix 56ANOVA table for Wheat photosynthetic rate

Source	DF	SS	MS	F	P
R	2	8.19	4.095		
Y	1	197.86	197.864	23.56	**
Error R x Y	2	16.79	8.397		
CS	3	191.41	63.804	8.51	***
Y x CS	3	5.04	1.679	0.22	NS
Error R x Y x CS	12	90.01	7.501		
SA	4	1353.17	338.292	170.34	***
Y x SA	4	4	0.999	0.5	NS
CS x SA	12	42.42	3.535	1.78	*
Y x CS x SA	12	25.88	2.156	1.09	NS
Error R x Y x CS x SA	64	127.11	1.986		
Total	119	2061.89			
CV(R x Y)	10.46				
CV(R x Y x CS)	9.89				
CV(R x Y x CS x SA)	5.09				

Appendix 57ANOVA table for Wheat transpiration rate

Source	DF	SS	MS	F	P
R	2	0.2607	0.13033		
Y	1	0.3245	0.32448	9984	***
Error R x Y	2	0.0001	0.00003		
CS	3	4.637	1.54568	148.48	***
Y x CS	3	0.0051	0.0017	0.16	NS
Error R x Y x CS	12	0.1249	0.01041		
SA	4	13.8177	3.45442	810.74	***
Y x SA	4	0.0095	0.00239	0.56	NS
CS x SA	12	1.6511	0.13759	32.29	***
Y x CS x SA	12	0.0027	0.00023	0.05	NS
Error R x Y x CS x SA	64	0.2727	0.00426		
Total	119	21.1061			
CV(R x Y)	0.08				
CV(R x Y x CS)	1.35				
CV(R x Y x CS x SA)	0.87				

Appendix 58ANOVA table for Wheat stomatal conductance

Source	DF	SS	MS	F	P
R	2	0.5535	0.27675		
Y	1	0.42245	0.42245	33.51	**
Error R x Y	2	0.02521	0.01261		
CS	3	0.04549	0.01516	28.71	***
Y x CS	3	0.00241	0.0008	1.52	NS
Error R x Y x CS	12	0.00634	0.00053		
SA	4	0.93338	0.23334	207.96	***
Y x SA	4	0.03535	0.00884	7.88	***
CS x SA	12	0.01999	0.00167	1.48	NS
Y x CS x SA	12	0.00639	0.00053	0.47	NS
Error R x Y x CS x SA	64	0.07181	0.00112		
Total	119	2.12232			
CV(R x Y)	15.11				
CV(R x Y x CS)	3.09				
CV(R x Y x CS x SA)	4.51				